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A COMPARISON OF THE PERFORMANCE OF FRAGMENTS OF FOUR MATERIALS IMPACTING ON VARIOUS PLATES (U)

PROJECT THOR TECHNICAL REPORT NO. 41

MAY 1959

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ABSTRACT

Residual velocity data for fragments of four different materials, aluminum alloy, steel, uranium, and a tungsten alloy, impacting on various plates are analyzed. The range of fragment sizes is from 30 to 240 grains while the fragment striking velocities are usually no higher than 6000 feet per second. Empirical formulas are fitted to the body of data for each fragment-plate combination. Sets of graphs are displayed relating selected impact parameters. By the use of these graphs, a comparison of the performance of the four fragment materials is made, for fixed weight and shape of the fragments. The ordering of the fragment materials is found to correspond with their densities, with better performance corresponding to increasing density.

INTRODUCTION

Residual velocity data for fragments of various materials impacting on steel and aluminum alloy targets have been analyzed. These data were provided by the Ballistic Research Laboratories (BRL) of Aberdeen Proving Ground, Maryland. The underlying motive for the analysis is to provide an estimate of the effect of variation of certain fragment characteristics on the performance of the fragment. Restrictions are imposed on the impact parameters to make the study particularly applicable to problems related to the vulnerability of material configurations used in structures of aircraft and missiles.

Other experiments on penetration have revealed that a fragment that remains intact after impact will usually "perform" better than another fragment that breaks up, all other factors being equal. Is it possible to use fragments of materials other than steel to advantage in some situations? The blithe assumption that steel is the optimum fragment material requires frequent reappraisal.

The retardation of a fragment in flight is less for a given fragment than for another fragment of the same weight, same shape, and lower density. This effect is more pronounced at low altitudes than at altitudes where the air resistance is negligible. This phenomenon is a point in favor for high density fragments.

The fragment materials selected to provide data for this study are listed below. Fragments in the shapes of cylinders and box-on-cylinders were prepared for single-shot firings at BRL.

With light gas guns presently in use at BRL, velocities for steel fragments (and for fragments of less dense materials) over 10,000 fps are possible. However, for this study, the comparison is restricted to fragment striking velocities no higher than 6000 fps because of the inclusion of denser fragments. Firing the denser fragments at much higher velocities would have involved technical difficulties with accompanying delays. Wherever data were available at higher striking velocities, they were included in the appropriate sample. A tabulation of the data is presented in Appendix XI; the tabulation reveals instances where the striking velocity of the fragment is as high as 12,000 fps.

Table 1

Fragment Materials and Densities

Fragment Material	Density (lb/ft^3)
uranium	1166
tungsten alloy	1050
steel (SAE 1020)	485
aluminum alloy (2024ST)	175

This report will deal primarily with a comparison of the performance of tungsten alloy fragments with steel fragments. Data for the two other fragment materials are included wherever possible to furnish additional information. Data have been accumulated for all four of the fragment materials impacting on aluminum alloy plates. Hitherto, only tungsten alloy and steel fragments have been fired at steel plates.

In Technical Report No. 36*, a method is described for obtaining empirical equations from residual velocity data to relate residual velocity to impact parameters. The type of equation proposed is of the form:

$$V_r = V_s - k\,(eA)^{\alpha}\, m^{\beta}\, (\sec\theta)^{\gamma}\, V_s^{\lambda}$$

where V_r is the fragment residual velocity in feet per second,

V_s is the fragment striking velocity in feet per second,

e is the plate thickness in inches,

A is the average impact area of the fragment in square inches,

m is the weight of the fragment in grains,

θ is the angle between the trajectory of the fragment and the normal to the plate, and

k, α, β, γ, λ are constants that are determined separately for each fragment-plate combination.

*Ballistic Analysis Laboratory Technical Report No. 36, A Study of Residual Velocity Data for Steel Fragments Impacting on Four Materials; Empirical Relationships, (U), April 1958, Confidential Report. AD-162 700

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The plate Brinell Hardness Number B has also been found to be a useful parameter.

This same procedure has been utilized to provide analytical expressions relating to each of the following fragment-plate combinations:

1. uranium fragments and aluminum alloy plate,
2. tungsten alloy fragments and aluminum alloy plate,
3. aluminum alloy fragments and aluminum alloy plate,
4. tungsten alloy fragments and steel plate, $B \sim 100$,
5. tungsten alloy fragments and steel plate, $B \sim 300$, and
6. steel fragments and steel plate of various hardnesses.

The empirical equations relating to steel fragments impacting on aluminum alloy plate have already been discussed in Technical Report No. 36.

In the latter report, an analysis was made of residual velocity data for steel fragments impacting on mild steel. For those data, the Brinell Hardness values of the steel plate are less than 200. Since the publication of this previous report, additional data on steel plates have become available with the Brinell range for the plates extending to 500. The effect of variation in hardness of plate on resistance of steel plates to perforation by steel fragments is accounted for by the insertion in the basic equation of the factor $\exp(\epsilon B^2 + \omega B)$. The

form of this factor, which, if $\epsilon < 0$, has a maximum at $B = -\omega/2\epsilon$, reflects the fact that maximum resistance occurs for an intermediate value of B. This effect is not considered for tungsten alloy fragments impacting on steel since the range of plate hardness in the data sample is small.

All constants are determined by application of the method of least squares to the linear equation relating the Briggs' logarithms:

$$\log (V_s - V_r) = \log k + \alpha \log (eA) + \beta \log m + \gamma \log \sec \theta + \lambda \log V_s + 0.4343 (\epsilon B^2 + \omega B).$$

It should be noted that the graphs in Appendix VII for steel fragments impacting on steel plates (B = 100) do not coincide with the corresponding graphs for "mild" steel plate in Technical Report No. 36. This is understandable since the mild steel graphs in the latter report represent a compromise in plate resistance over a considerable range in plate hardness (BHN 80 - 200).

DESCRIPTION OF MATERIALS

In the firing program, the steel fragments used were of SAE 1020 stock with a surface hardness of approximately C-35 Rockwell.

The tungsten alloy fragments were obtained from two sources, (1) Fansteel Metallurgical Corp., Metals and Fabrication Division, North Chicago, Illinois, and (2) P.R. Mallory and Co., Inc., Indianapolis 6, Indiana. It was quickly ascertained by test firings that the respective products, Fansteel 77 and Mallory 1000 are nearly alike in ballistic performance. Each of these products is an alloy containing approximately 89% tungsten, 7% nickel, and 4% copper. The alloy is made by powder metallurgy and has about the same tensile strength as the best grades of cold drawn steel. It is non-rusting and non-magnetic.

The material designated as aluminum alloy in this report, whether reference is made to fragments or plate, is more precisely identified as 2024ST.

The uranium fragments were supplied by the Dow Chemical Co., Rocky Flats Point, Denver, Colorado. The fragments are designated by lot nos. 703A,B,C,D; D-38 Cylinder. The material is the variety of uranium known as Tuballoy or depleted uranium with less than 0.13% impurities. For the purposes of this report, more detailed information on the material characteristics is not required.

EXAMINATION OF RECOVERED FRAGMENTS

In many instances, it has been possible to recover the fragments after impact. These fragments have been mounted on panels with related information attached. Photographs of these panels are presented in Appendix X. For simplicity, both the weight m_r of the largest piece of the recovered fragment and the total weight $\bar{m}_r$ of all the pieces of recovered fragment are supplied, rather than the weight of each individual piece. In some instances of fragment break-up, several pieces of the original fragment were found. The photographs are helpful in pointing out the phenomenon of fragment break-up and the inherent loss in weight of a fragment during perforation. However, it is regretted that the full impact of the use of these photographs is not rendered since the extreme instances of fragment break-up (i.e., shatter) cannot be recorded in this manner.

The photographs readily reveal, for example, that break-up is a more serious matter for impacts on hard steel than for comparable conditions of impact on aluminum alloy or soft steel. However, for a quantitative analysis of fragment loss-in-weight during perforation, a systematic laboratory program is needed. The damage capacity of spall fragments can be investigated simultaneously. Useful laboratory data along these lines will be difficult to obtain, and new measuring techniques may be required. Nevertheless, the need for such data is clear. The impact phenomenon of fragment on plate can then be more fully evaluated.

TECHNIQUE FOR COMPARING FRAGMENT MATERIALS

The plan which is being used to provide a comparison of fragment materials is:

1. Adopt an appropriate criterion as a basis for comparison of fragment materials.
2. Develop empirical equations for estimating fragment residual velocity as a function of the impact parameters for each fragment-plate combination.
3. With the use of the empirical equations, prepare sets of graphs relating selected pairs of impact parameters.
4. Examine corresponding values on these sets of graphs for fixed sets of conditions imposed by the criterion adopted in (1). Compare these values in some methodical fashion.

Many criteria are conceivable for use in comparing the performance of fragment materials. Three criteria are selected here for discussion.

1. The weights and impact areas of the fragments of the various materials are held constant.
2. The shapes and volumes of the fragments of the various materials are held constant.
3. The weights and shapes of the fragments of the various materials are held constant.

To adopt the first method, it would be necessary to compare the performance of fragments of different shapes, e.g., compact tungsten alloy fragments with pencil-shaped steel fragments. This would provide an unwarranted advantage to the fragments of low density.

The second criterion implies that the weight consideration is not important, and unrealistically provides an undue advantage to the fragment materials of high density.

The third criterion is adopted for use since, with this method, the effect of confining the impact "energy" in a smaller package will be noted.

The analytical expressions developed for the six new fragment-plate combinations are given in Tables 2a and 2b.

The emphasis in all of the criteria mentioned above is on fragment velocity. Under the adopted criterion, the "better" fragment material is the one for which the fragment requires a lower velocity to perforate a given thickness of plate material, or it is the one for which a greater residual velocity is to be expected, granted that perforation takes place. Yet this is not the complete story. The residual weight of the fragment after impact is also an important feature. It has not yet been established that the "better" fragment under the criterion adopted above is also the fragment which can be expected generally to have the greater damage potential after impact. A detailed study of fragment residual weight is required before any conclusions in this

TABLE 2a

EMPIRICAL FORMULAS FOR PREDICTING RESIDUAL VELOCITY

Fragment Type	Plate Material	Basic Formulas for V_r
Uranium	Aluminum Alloy	$V_r = V_s - 10^{9.992} (eA)^{1.486} m^{-1.531} (\sec \theta)^{1.518} V_s^{-.484}$
Tungsten Alloy	Aluminum Alloy	$V_r = V_s - 10^{11.62} (eA)^{1.550} m^{-1.640} (\sec \theta)^{1.500} V_s^{-.928}$
Steel (SAE 1020)	Aluminum Alloy *	$V_r = V_s - 10^{6.571} (eA)^{0.944} m^{-0.990} (\sec \theta)^{1.13} V_s^{-.076}$
Aluminum Alloy	Aluminum Alloy	$V_r = V_s - 10^{7.233} (eA)^{1.017} m^{-1.141} (\sec \theta)^{1.186} V_s^{-.174}$
Tungsten Alloy	Steel (B ~ 100)	$V_r = V_s - 10^{10.806} (eA)^{1.729} m^{-1.754} (\sec \theta)^{1.337} V_s^{-.434}$
Tungsten Alloy	Steel (B ~ 300)	$V_r = V_s - 10^{6.664} (eA)^{.810} m^{-.9935} (\sec \theta)^{1.068} V_s^{-.017}$
Steel (SAE 1020)	Steel	$V_r = V_s - 10^{6.132} (eA)^{.889} m^{-.945} (\sec \theta)^{1.262} V_s^{.019} \exp\left[-.877(10)^{-5} B^2 + .0054133\right]$
Steel (SAE 1020)	Steel (B=100)	$V_r = V_s - 10^{6.329} (eA)^{.889} m^{-.945} (\sec \theta)^{1.262} V_s^{.019}$
Steel (SAE 1020)	Steel (B=300)	$V_r = V_s - 10^{6.494} (eA)^{.889} m^{-.945} (\sec \theta)^{1.262} V_s^{.019}$
Steel (SAE 1020)	Steel (B=500)	$V_r = V_s - 10^{6.355} (eA)^{.889} m^{-.945} (\sec \theta)^{1.262} V_s^{.019}$

* As given in Technical Report No. 36

TABLE 2b

EMPIRICAL FORMULAS FOR PREDICTING RESIDUAL VELOCITY

Fragment Type	Plate Material	V_r Formulas for BRL Pre-formed Fragments
Uranium	Aluminum Alloy	$V_r = V_s - 10^{6.254}\, e^{1.486}\, m^{-.540}\, (\sec\theta)^{1.518}\, V_s^{-.484}$
Tungsten Alloy	Aluminum Alloy	$V_r = V_s - 10^{8.012}\, e^{1.550}\, m^{-.607}\, (\sec\theta)^{1.500}\, V_s^{-.928}$
Steel (SAE 1020)	Aluminum Alloy*	$V_r = V_s - 10^{4.576}\, e^{0.944}\, m^{-.361}\, (\sec\theta)^{1.13}\, V_s^{-.076}$
Aluminum Alloy	Aluminum Alloy	$V_r = V_s - 10^{5.276}\, e^{1.017}\, m^{-.463}\, (\sec\theta)^{1.186}\, V_s^{-.174}$
Tungsten Alloy	Steel (B $\sim$ 100)	$V_r = V_s - 10^{6.781}\, e^{1.729}\, m^{-.601}\, (\sec\theta)^{1.337}\, V_s^{-.434}$
Tungsten Alloy	Steel (B $\sim$ 300)	$V_r = V_s - 10^{4.778}\, e^{.810}\, m^{-.454}\, (\sec\theta)^{1.068}\, V_s^{-.017}$
Steel (SAE 1020)	Steel	$V_r = V_s - 10^{4.253}\, e^{.889}\, m^{-.352}\, (\sec\theta)^{1.262}\, V_s^{.019} \exp\left[-.877(10)^{-5}B^2 + .0054133\right]$
Steel (SAE 1020)	Steel (B=100)	$V_r = V_s - 10^{4.450}\, e^{.889}\, m^{-.352}\, (\sec\theta)^{1.262}\, V_s^{.019}$
Steel (SAE 1020)	Steel (B=300)	$V_r = V_s - 10^{4.615}\, e^{.889}\, m^{-.352}\, (\sec\theta)^{1.262}\, V_s^{.019}$
Steel (SAE 1020)	Steel (B=500)	$V_r = V_s - 10^{4.476}\, e^{.889}\, m^{-.352}\, (\sec\theta)^{1.262}\, V_s^{.019}$

* As given in Technical Report No. 36

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respect can be reached. A more realistic criterion would combine the weight and velocity concepts so that the better fragment would be chosen as that fragment with the greater capacity for damage after perforating a given barrier. This criterion implies an optimum combination of weight and velocity reductions after impact.

To execute the plan outlined above it has been found expedient to introduce new symbols; these are:

$(V_r)_W$, the residual velocity (fps) for a tungsten alloy fragment,

$(V_r)_U$, the residual velocity (fps) for a uranium fragment,

$(V_r)_{AA}$, the residual velocity (fps) for an aluminum alloy fragment, and

$(V_r)_S$, the residual velocity (fps) for a steel fragment.

In a similar manner $(V_o)_U$, for example, will be the value of V_o for a uranium fragment.

The V_o symbol is used to denote the value of the striking velocity V_s obtained in the empirical formulas by setting the residual velocity V_r equal to zero. It has been found that the V_o values serve as good analytical approximations to protection velocities. The protection velocity is defined to be the highest striking velocity below the ballistic limit for which the probability of perforating a given target is zero. The analytical expressions for V_o are given in Tables 3a and 3b.

TABLE 3a

EMPIRICAL FORMULAS FOR PREDICTING V_o

Fragment Type	Plate Material	Basic Formulas for V_o
Uranium	Aluminum Alloy	$V_o = 10^{6.733} (eA)^{1.001} m^{-1.032} (\sec \theta)^{1.023}$
Tungsten Alloy	Aluminum Alloy	$V_o = 10^{6.027} (eA)^{.804} m^{-.851} (\sec \theta)^{.778}$
Steel (SAE 1020)	Aluminum Alloy*	$V_o = 10^{6.105} (eA)^{.877} m^{-.920} (\sec \theta)^{1.05}$
Aluminum Alloy	Aluminum Alloy	$V_o = 10^{6.161} (eA)^{.867} m^{-.972} (\sec \theta)^{1.010}$
Tungsten Alloy	Steel (B ~ 100)	$V_o = 10^{7.536} (eA)^{1.206} m^{-1.223} (\sec \theta)^{.932}$
Tungsten Alloy	Steel (B ~ 300)	$V_o = 10^{6.554} (eA)^{.796} m^{-.977} (\sec \theta)^{1.050}$
Steel (SAE 1020)	Steel	$V_o = 10^{6.251} (eA)^{.906} m^{-.963} (\sec \theta)^{1.286} \exp\left[-.894(10)^{-5}B^2 + .0055138\right]$
Steel (SAE 1020)	Steel (B=100)	$V_o = 10^{6.452} (eA)^{.906} m^{-.963} (\sec \theta)^{1.286}$
Steel (SAE 1020)	Steel (B=300)	$V_o = 10^{6.620} (eA)^{.906} m^{-.963} (\sec \theta)^{1.286}$
Steel (SAE 1020)	Steel (B=500)	$V_o = 10^{6.355} (eA)^{.906} m^{-.963} (\sec \theta)^{1.286}$

* As given in Technical Report No. 36

TABLE 3b

EMPIRICAL FORMULAS FOR PREDICTING V_o

Fragment Type	Plate Material	Formulas for V_o for BRL Pre-formed Fragments
Uranium	Aluminum Alloy	$V_o = 10^{4.215}\ e^{1.001}\ m^{-.364}\ (\sec\theta)^{1.023}$
Tungsten Alloy	Aluminum Alloy	$V_o = 10^{4.156}\ e^{.804}\ m^{-.315}\ (\sec\theta)^{.778}$
Steel (SAE 1020)	Aluminum Alloy*	$V_o = 10^{4.252}\ e^{.877}\ m^{-.336}\ (\sec\theta)^{1.05}$
Aluminum Alloy	Aluminum Alloy	$V_o = 10^{4.493}\ e^{.867}\ m^{-.394}\ (\sec\theta)^{1.010}$
Tungsten Alloy	Steel (B ~ 100)	$V_o = 10^{4.729}\ e^{1.206}\ m^{-.419}\ (\sec\theta)^{.932}$
Tungsten Alloy	Steel (B ~ 300)	$V_o = 10^{4.698}\ e^{.796}\ m^{-.446}\ (\sec\theta)^{1.050}$
Steel (SAE 1020)	Steel	$V_o = 10^{4.336}\ e^{.906}\ m^{-.359}\ (\sec\theta)^{1.286}\ \exp\left[-.894(10)^{-5}B^2 + .0055183\right]$
Steel (SAE 1020)	Steel (B=100)	$V_o = 10^{4.537}\ e^{.906}\ m^{-.359}\ (\sec\theta)^{1.286}$
Steel (SAE 1020)	Steel (B=300)	$V_o = 10^{4.705}\ e^{.906}\ m^{-.359}\ (\sec\theta)^{1.286}$
Steel (SAE 1020)	Steel (B=500)	$V_o = 10^{4.563}\ e^{.906}\ m^{-.359}\ (\sec\theta)^{1.286}$

* As given in Technical Report No. 36

Many of the terms and techniques introduced here are discussed in greater detail in the previous technical report (No. 36) on penetration by steel fragments.

For each fragment-plate combination two sets of graphs are provided. The first set relates V_r/V_s to V_s for nine combinations of fragment weight and obliquity. The second set of graphs relates V_o to fragment weight for selected plate thicknesses. It is to be understood that both of these sets of graphs refer to the box-on-cylinder shape fragment as used in BRL experiments. For a fixed shape of fragment, it is possible to simplify the formulas by replacing the impact parameter A by a suitable function of the fragment weight m. The function used is of the form $cm^{2/3}$, where c depends on the fragment material.

An examination of values on corresponding graphs in each set for the four fragment materials provides a basis for comparing the performances of the four materials in a quantitative manner. For selected combinations of impact parameters, the ratios of $(V_r)_X/(V_r)_S$ and $(V_o)_X/(V_o)_S$ can be obtained for each fragment material (X). Each of these ratios, called R and r respectively, is averaged over a selection of values of fragment weight; thus $\bar{R}$ and $\bar{r}$, the averages, depend only on obliquity and thickness for each combination of fragment type and plate material X. The combinations of values of obliquity and thickness are selected so that $(V_r)_S \geq 1000$ fps for the sampling of R values while

$(V_o)_S \geq 400$ fps for the sampling of r values. These restrictions on $(V_o)_S$ and $(V_r)_S$ are needed in order to ensure that the individual ratios r and R be reasonably close to $\bar{r}$ and $\bar{R}$ respectively. Furthermore, the relative error in the estimate for V_o increases rapidly as V_o approaches zero. Finally, impact conditions for which $0 \leq V_o \leq 400$ are of relatively minor military significance.

The significance of a value of $\bar{r}$ greater than or less than unity is easily determined. For example, if $\bar{r} = 2$ for a given set of impact conditions, the interpretation is that a fragment of material X requires twice as much velocity to perforate the plate as the minimum velocity required for perforation by a steel fragment. For this situation, the conclusion follows that the fragment of the material in question is inferior to the corresponding steel fragment. A value of $\bar{r}$ of unity would indicate that the fragments of both materials are performing equally.

The significance of a value of $\bar{R}$ greater than or less than unity can also be quickly established. Suppose $\bar{R} = 2$ for a given set of conditions. The interpretation is that the fragment of the material in question will have twice the residual velocity after impact as that of a steel fragment. For this situation, the conclusion follows that the fragment of the material in question is superior to the corresponding steel fragment. A value of $\bar{R}$ of unity would indicate again that the fragments of both materials are performing equally.

The comparison using $\bar{r}$ and $\bar{R}$ is always made with respect to steel fragments. The reasons for this choice are (1) steel is the classical material in use for fragments, and (2) more is known about the performance of steel fragments than the fragments of other materials since more data on steel fragments are available.

Other sets of graphs have also been found useful in comparing the performance of the four fragment materials. For each target plate, the residual velocity has been plotted against plate thickness for selected combinations of fragment weight, obliquity, and striking velocity. In addition, the plate thickness has been plotted against fragment weight for selected values of V_o and obliquity. The advantage to be gained by the use of these sets of graphs is that one can quickly determine the order of superiority of the fragment materials since it is possible to have a separate contour for each fragment material on each graph. A fragment material X is considered to be superior to another fragment material Y if for a given target plate, fragment weight, obliquity, and striking velocity, X will have more residual velocity than Y. Similarly, X is considered to be superior to Y, if, for a given plate material, fragment weight, obliquity, and V_o, X is found to be capable of penetrating a greater thickness of the target than Y. Emphasis is placed on the understanding that the criterion for comparison requires that fragments of the different materials be of equal weight and of the same shape.

EMPIRICAL EQUATIONS; GOODNESS OF FIT

The criterion for goodness of fit of the analytical expressions developed is the magnitude of σ defined below. If $(V_{r,c})_i$ and $(V_{r,e})_i$ are, respectively, the calculated and the experimental residual velocities corresponding to the $(i)^{th}$ set of N sets of conditions, then

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N} \left[(V_{r,c})_i - (V_{r,e})_i\right]^2}{N}} .$$

It is understood that the selection of fit is made to correspond with the lowest observed value of σ.

The bias of the estimating equation is measured by b defined as follows:

$$b = \frac{\sum_{i=1}^{N} \left[(V_{r,c})_i - (V_{r,e})_i\right]}{N} .$$

An effort is made to adjust the final choices of the coefficient and exponents in the formulas so that the bias is reasonably close to zero.

A listing of the values of b and σ for the empirical equations for determining V_r for each of the fragment-plate combinations is given in Table 4.

TABLE 4

GOODNESS OF FIT OF EMPIRICAL FORMULAS FOR PREDICTING RESIDUAL VELOCITIES

Fragment Type	Plate Material	N	b	σ
Uranium	Aluminum Alloy	42	-36	446
Tungsten Alloy	Aluminum Alloy	55	-42	417
Steel (SAE 1020)	Aluminum Alloy*	151	20	360
Aluminum Alloy	Aluminum Alloy	19	-63	397
Tungsten Alloy	Steel (B ~ 100)	17	-104	242
Tungsten Alloy	Steel (B ~ 300)	33	181	509
Steel (SAE 1020)	Steel	117	41	516

* As given in Technical Report No. 36.

CONCLUSIONS

1. Comparison of Performance of Fragments Impacting on Aluminum Alloy Plate

For this situation, the comparison graphs suggest the following order in the performance of the fragment materials.

1, 2. uranium and tungsten alloy

3. steel

4. aluminum alloy

This ordering is preserved for all obliquities and fragment sizes considered. Furthermore, the ordering is the same whether residual velocity or protection velocity be used as the criterion.

The two dense materials, uranium and tungsten alloy, behave remarkably alike and the distinctions to be noted are of minor consideration. At low velocities ($\sim$ 2000 fps) the uranium fragments appear slightly better. This superiority vanishes as the striking velocity increases until, at higher velocities ($\sim$ 6000 fps), the tungsten alloy fragments appear superior. Although uranium is about 10% more dense than tungsten alloy, this uranium product, at least, is probably more frangible as well.

As the obliquity increases with the plate thickness remaining constant, the superiority of the denser fragment materials over

steel becomes increasingly pronounced.

The superiority of steel fragments over aluminum alloy fragments is readily apparent over the entire observed range of impact parameters. Oddly enough, this degree of superiority does not vary much with a change in obliquity.

These observations hold whether residual velocity or protection velocity be taken as the criterion.

2. Comparison of Performance of Fragments Impacting on Steel Plate (B = 100)

For this case, only two fragment materials are considered, tungsten alloy and steel.

Whether residual velocity or protection velocity be taken as the criterion, the tungsten alloy fragments appear at least as good as or superior to the steel fragments over the entire observed velocity range. The degree of superiority increases markedly with an increase in obliquity.

3. Comparison of Performance of Fragments Impacting on Steel Plate (B = 300)

Again, two fragment materials are considered: namely, tungsten alloy and steel.

Whether protection velocity or residual velocity be taken as the criterion, the tungsten alloy fragments are generally superior with the degree of superiority increasing with obliquity.

4. Comparison Summary

In comparing the performance of different fragment materials, the weights and shapes of the fragments of these materials are held constant. Under these conditions, tungsten alloy fragments have generally performed to advantage over steel fragments for all plate materials and impact parameters considered.

With respect to aluminum alloy plate, uranium fragments have been found to perform equally well with the tungsten alloy fragments, suggesting that density is an important property of fragment materials.

Steel fragments have appeared superior to aluminum alloy fragments throughout the observed range of impact conditions.

5. Other Comments

Since the dense materials were selected in the experimental work for their high density and not because of any other attribute, it is likely that a dense material, selected for some additional quality as, for example, tensile strength, will compare even more favorably with steel. It has been remarked that the degree of superiority of the tungsten alloy fragments over steel fragments is somewhat lessened as the target plate material becomes tougher. One plausible reason for this effect is that there have been more instances of fragment break-up against the more resistant plate materials. If this tendency can be checked by the usc of dense fragments of some other material,

it may become possible to achieve an even greater degree of superiority over steel fragments. Instances of fragment break-up against aluminum alloy plate were not frequent for the impact conditions investigated.

In Technical Report No. 36 one conclusion asserted that a single, simple, exponential type formula had been found adequate to predict satisfactory estimates of fragment residual velocity for steel fragments impacting on any one of four materials. This conclusion can be extended by the additional analyses made in the present report. Furthermore, the conclusion can refer, as well, to fragments other than steel. A sample size of thirty data points spanning the range of interest of the individual impact parameters seems to be sufficient to establish the identity of a working set of constants for the type of empirical formula proposed.

In the process of carrying out the procedure outlined for comparing fragment materials, it has been necessary to obtain several useful empirical equations which permit the outcome of the impact of fragments on certain plate materials to be anticipated. The most notable of the developed equations is probably the one containing a plate hardness parameter; the equation refers to steel fragments impacting on steel plate. This technique can be employed for other alloys which vary in hardness while retaining essentially the same density, e.g., aluminum alloys 2SO, 24 ST, and 75 ST.

In retrospect, fragments of the dense materials, tungsten

alloy and uranium, have performed better than steel fragments under the somewhat arbitrary but practical criteria chosen. The selection of an optimum fragment material is not the purpose of the present report. Design and economic aspects will influence the future course of action. Additional experimentation has already been proposed to BRL for the ballistic testing of tungsten carbide fragments. Particular care will be placed on observations of the break-up of this material.

A more complete comparison of the performance of fragment materials can be achieved if a companion effort is made to analyze impact data on the residual weight of fragments. One should then be in a better position to estimate the capacity of damage by a fragment on a primary target partially or wholly protected by some intermediate barrier. Useful additional residual velocity data can be obtained simultaneously. Observations of recovered fragments show that in some instances the fragment remains relatively intact, while for other impact conditions no trace of the original fragment can be found even though the fragment has perforated the plate. In Appendix X, photographs of recovered fragments are presented for various fragment-plate combinations. These photographs do not in themselves reveal the extent of the break-up phenomenon, since in cases of shatter it was difficult or impossible to recover any remnant of the fragment.

APPENDIX I

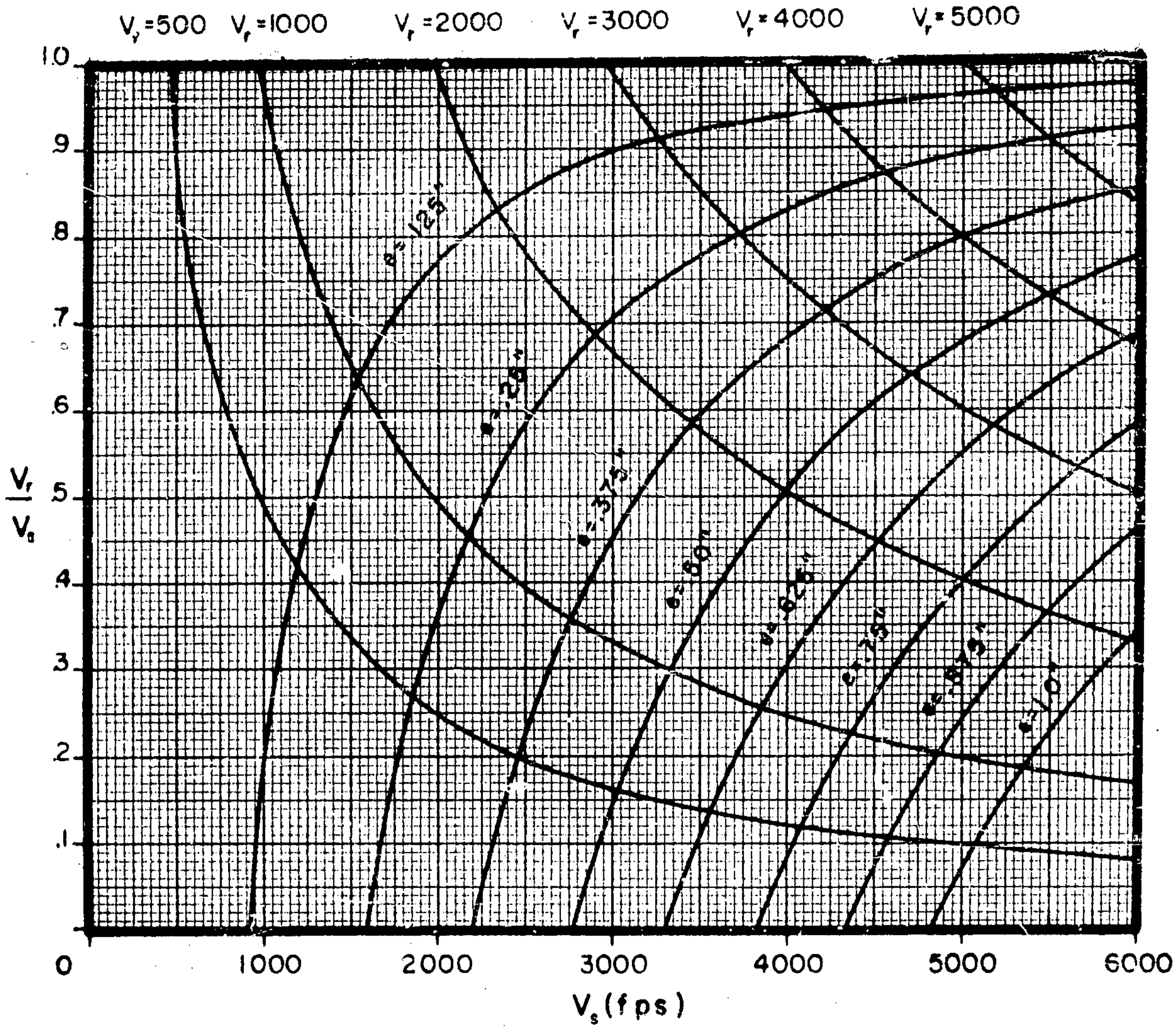
Tungsten Alloy Fragments vs Aluminum Alloy Plate

A. Residual Velocity/Striking Velocity vs Striking Velocity for Selected Plate Thicknesses

$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 0°

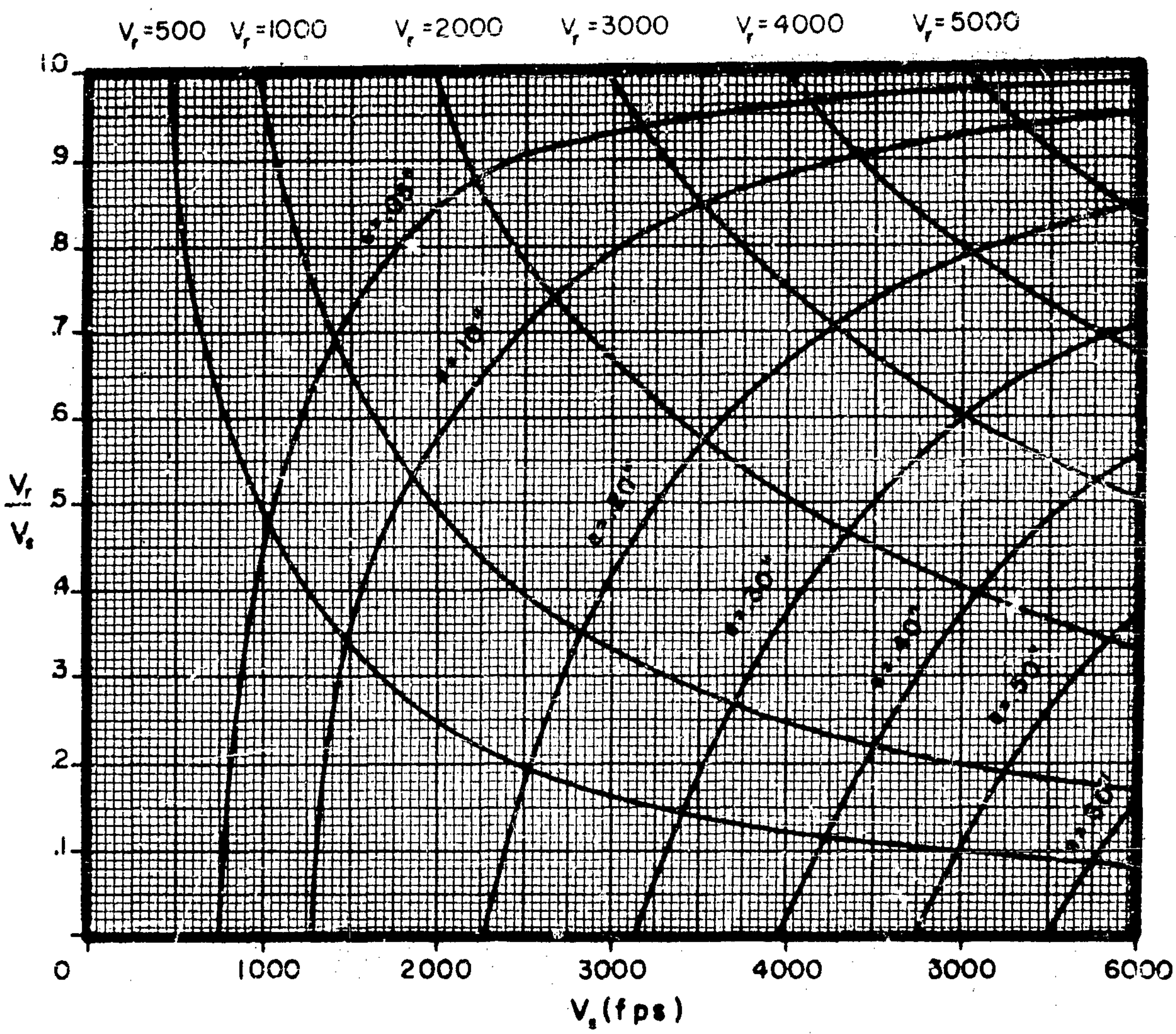
Fragment:
Type: BRL Pre-formed
Material: Tungsten Alloy
Size: 30 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 60°

Fragment:
Type: BRL Pre-formed
Material: Tungsten Alloy
Size: 30 grains



Residual Velocity / Striking Velocity vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Aluminum Alloy

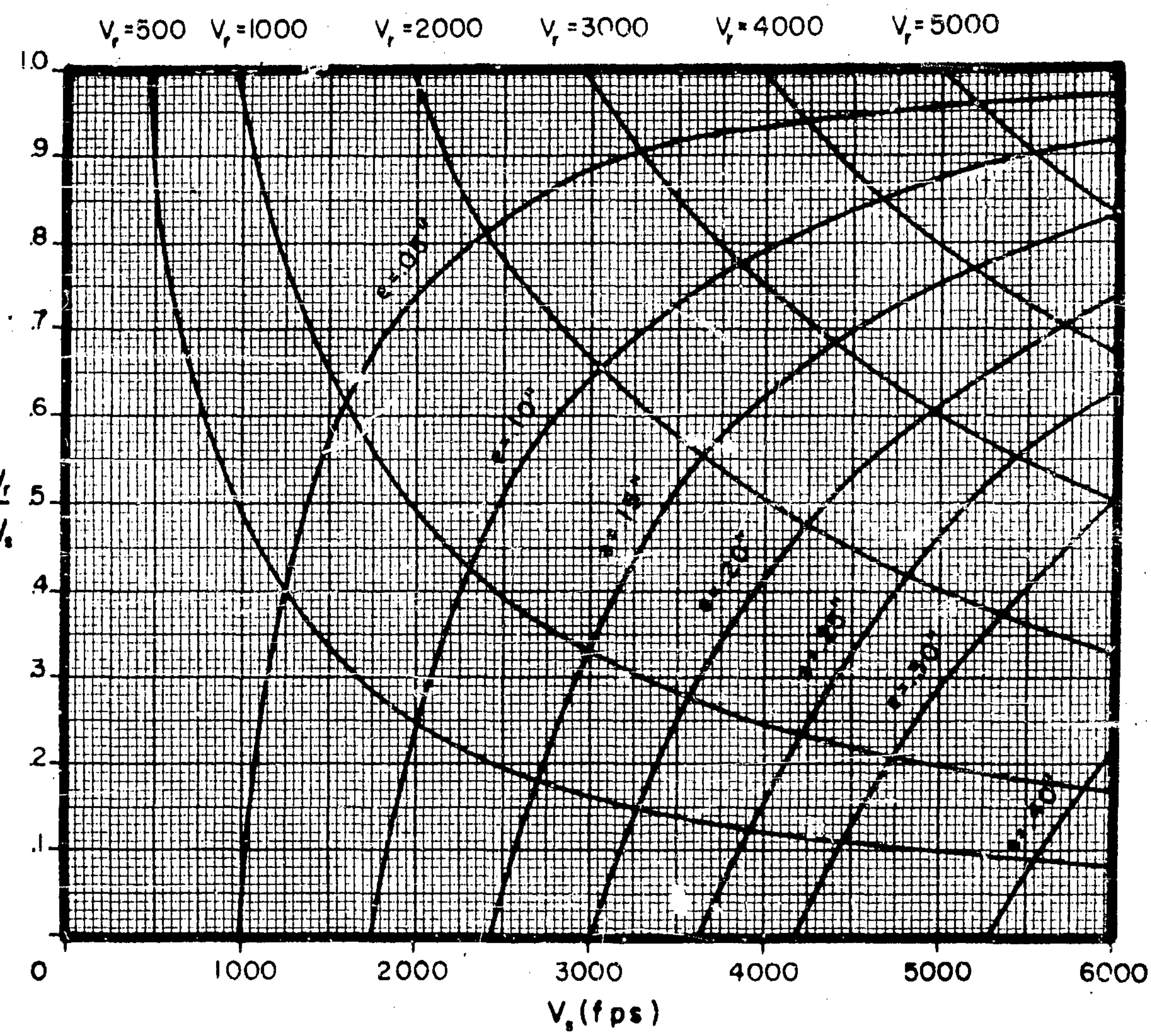
Obliquity: 70°

Fragment:

Type: BRL Pre-formed

Material: Tungsten Alloy

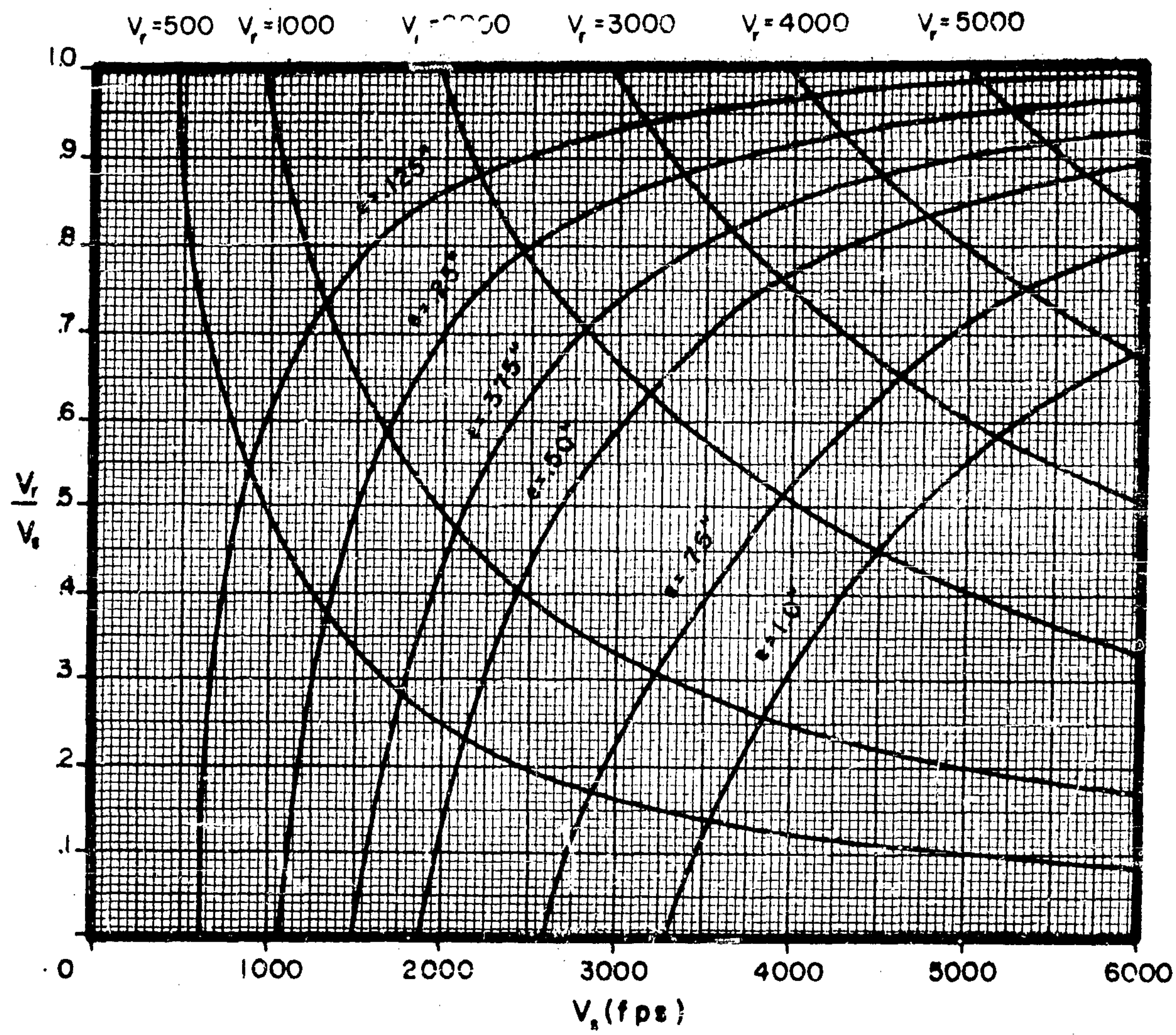
Size: 30 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 0°

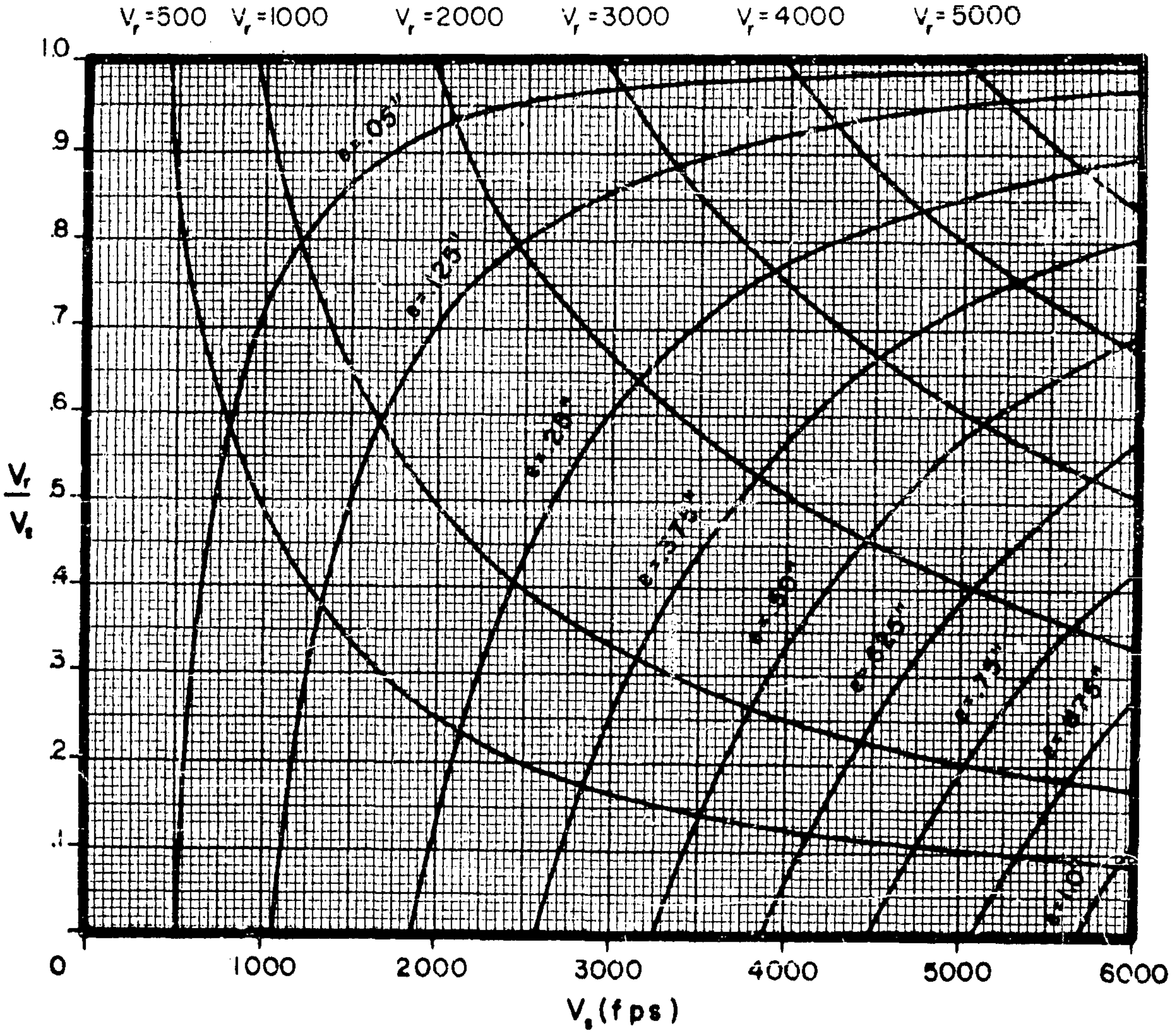
Fragment:
Type: BRL Pre-formed
Material: Tungsten Alloy
Size: 100 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 60°

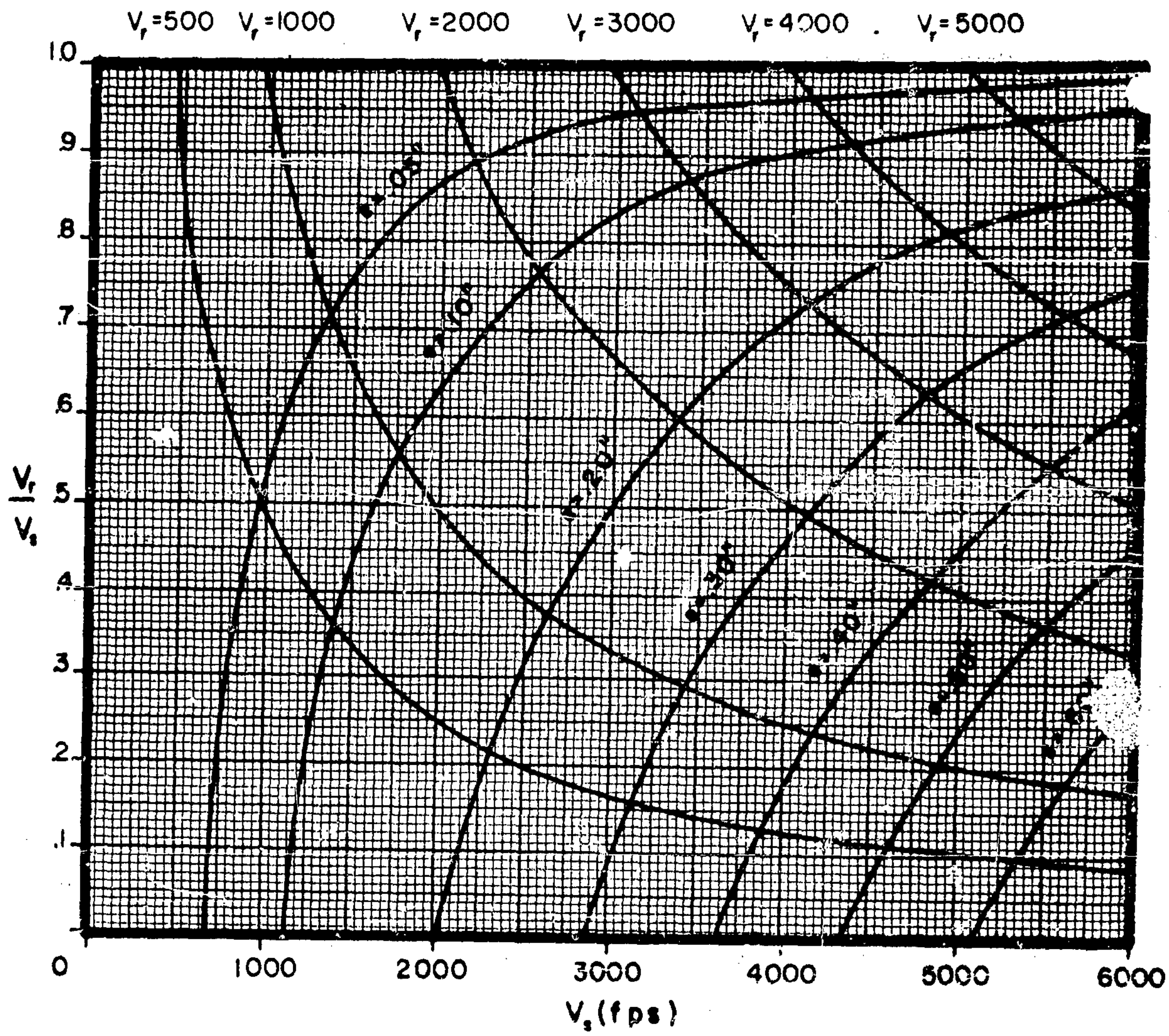
Fragment:
Type: BRL Pre-formed
Material: Tungsten Alloy
Size: 100 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 70°

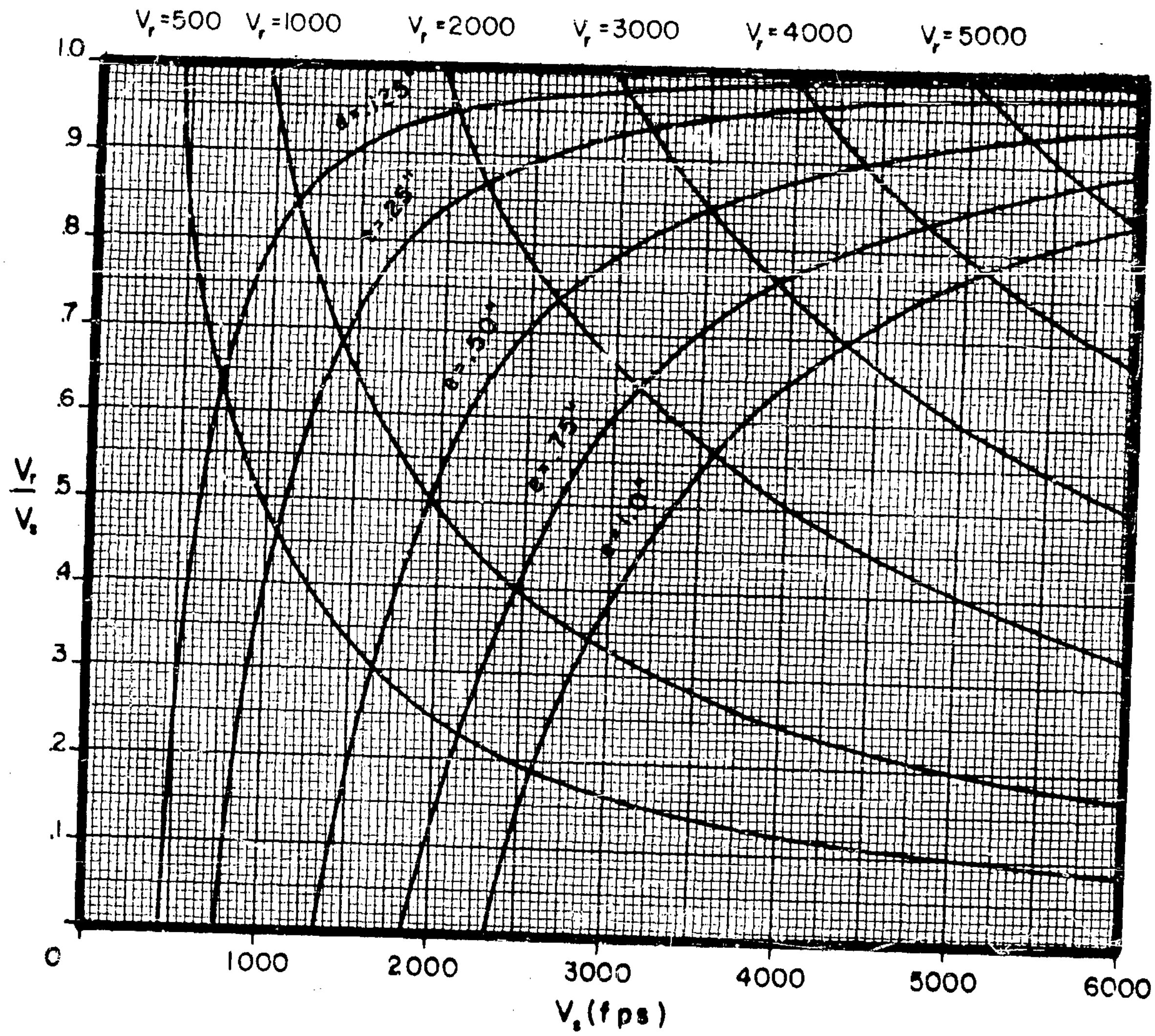
Fragment:
Type: BRL Pre-formed
Material: Tungsten Alloy
Size: 100 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 0°

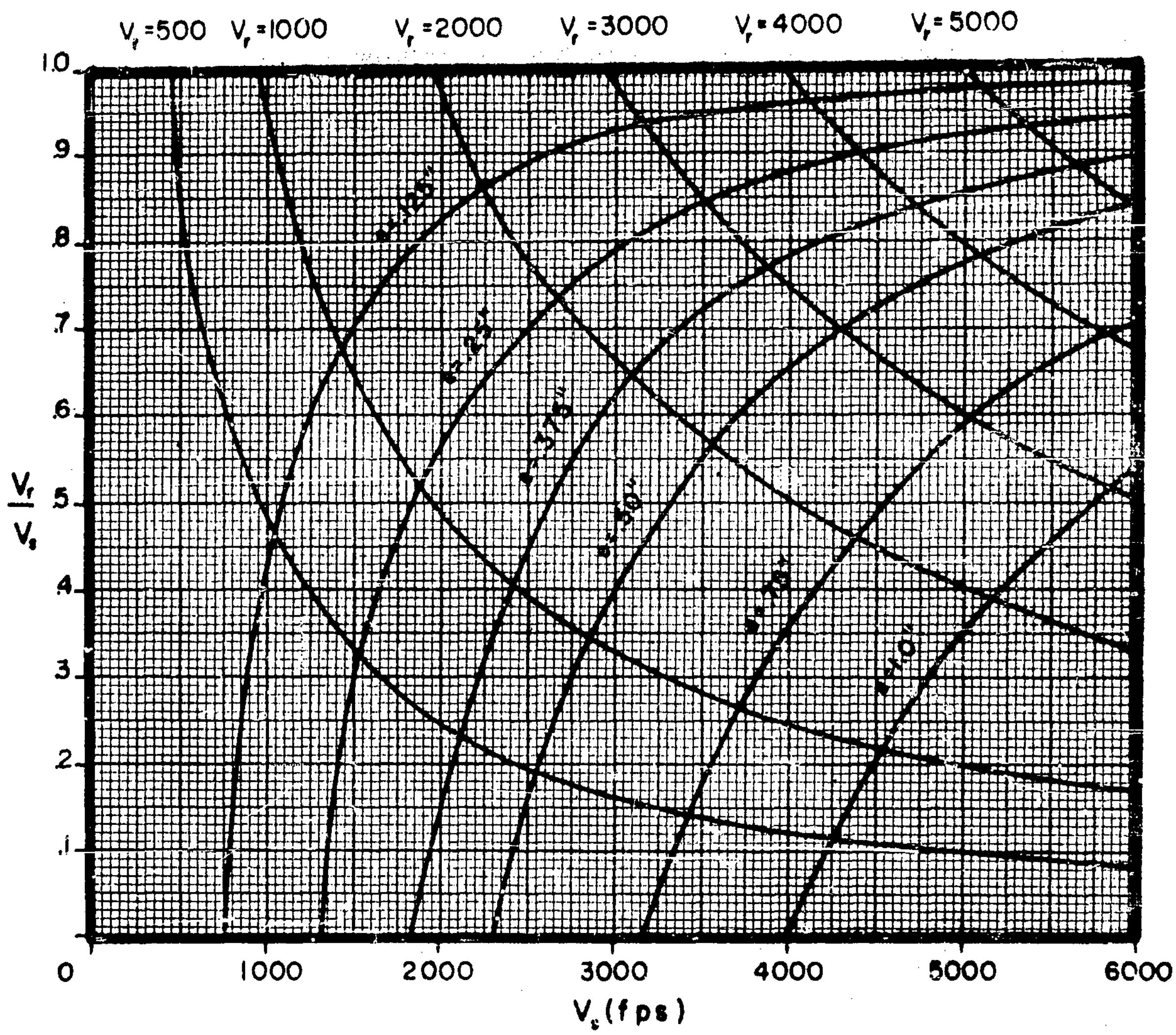
Fragment:
Type: BRL Pre-formed
Material: Tungsten Alloy
Size: 300 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 60°

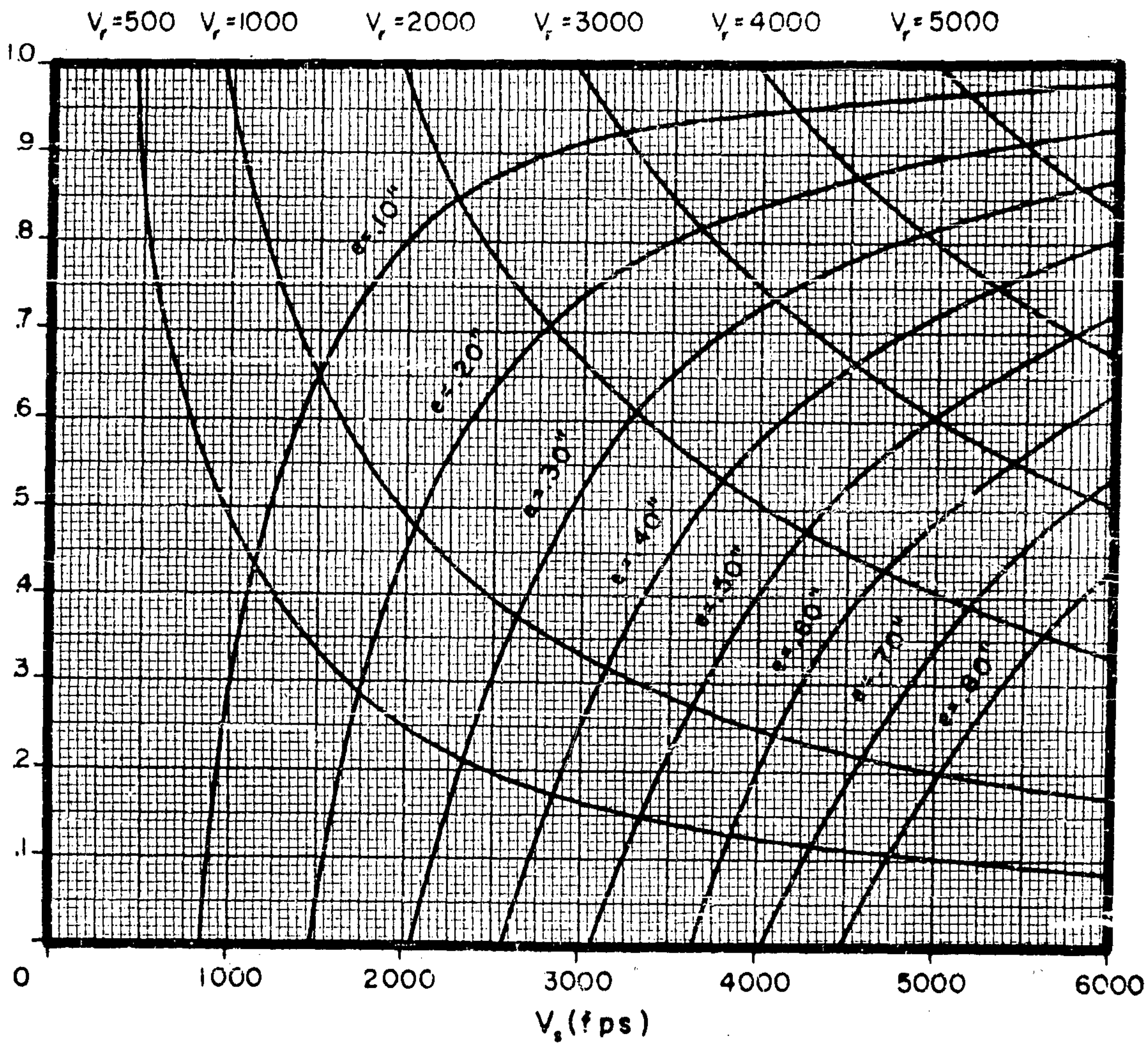
Fragment:
Type: BRL Pre-formed
Material: Tungsten Alloy
Size: 300 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 70°

Fragment:
Type: BRL Pre-formed
Material: Tungsten Alloy
Size: 300 grains



APPENDIX I

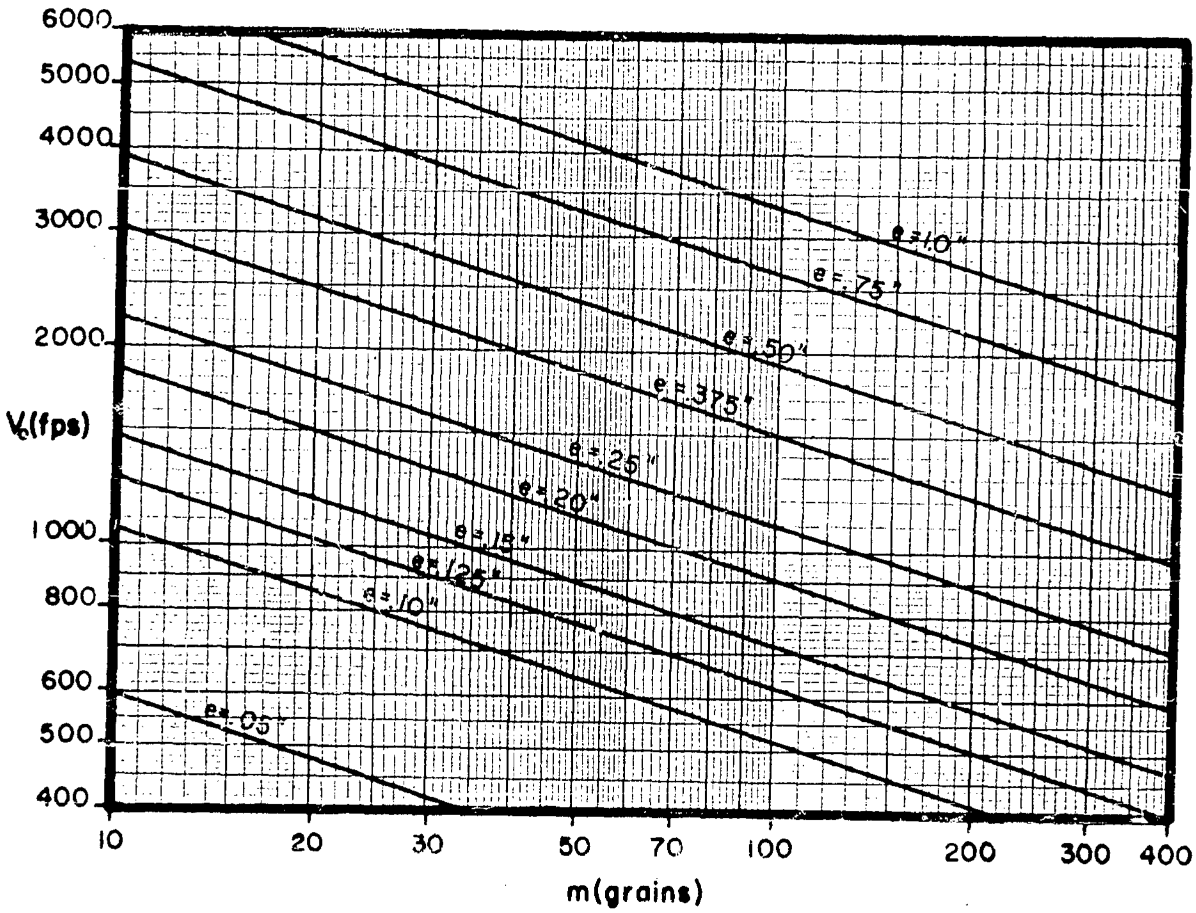
Tungsten Alloy Fragments vs Aluminum Alloy Plate

B. V_o vs Fragment Weight for Selected Plate Thicknesses

V_o vs Fragment Weight for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 0°

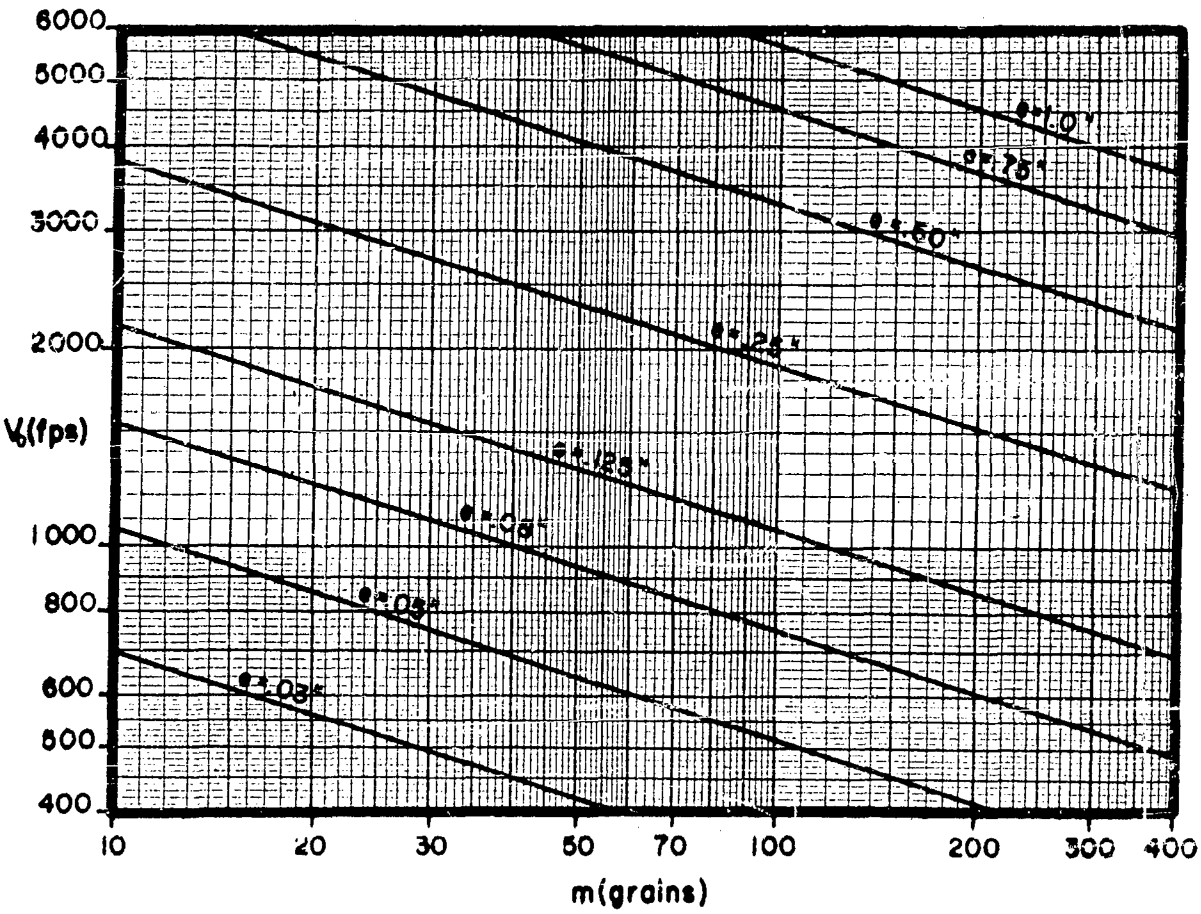
Fragment:
Type: B R L Pre-formed
Material: Tungsten Alloy



V₀ vs Fragment Weight for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 60°

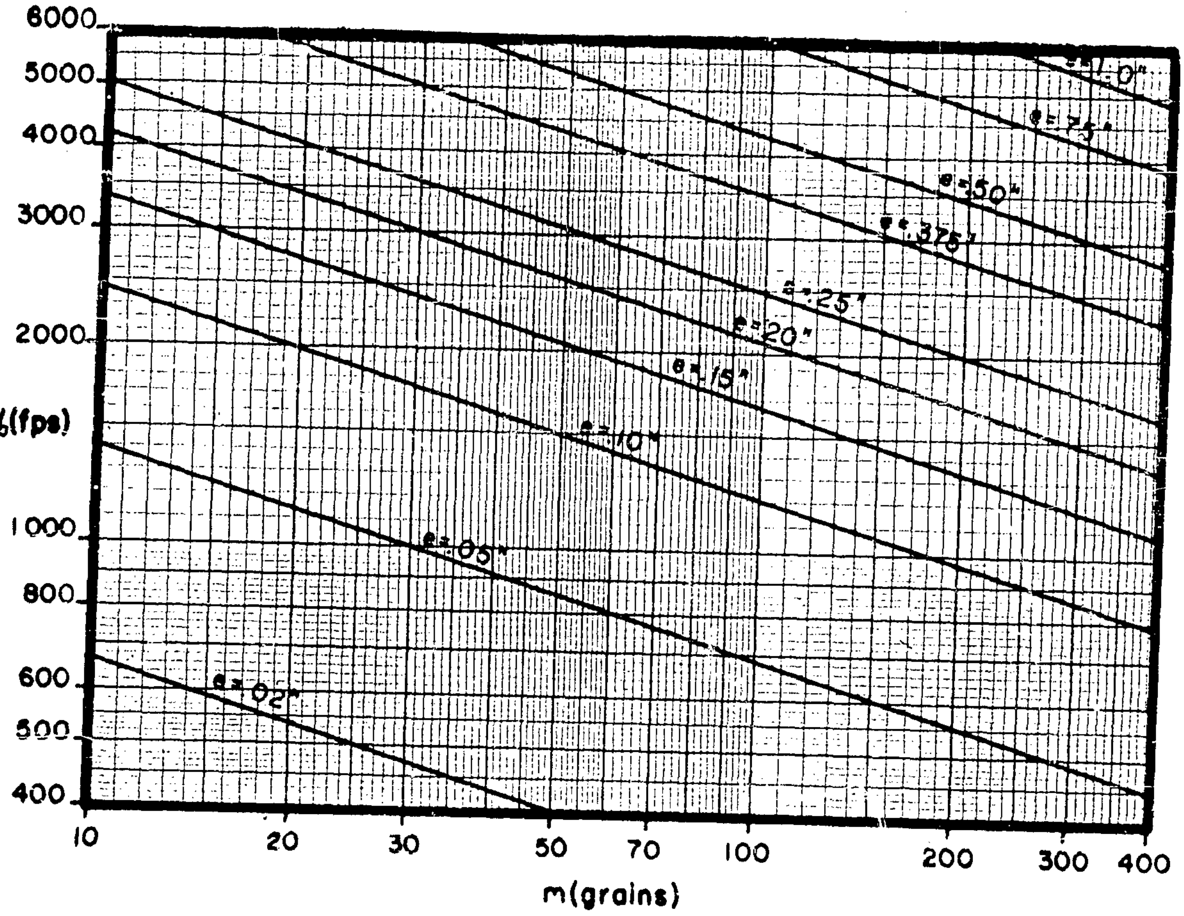
Fragment:
Type: B R L Pre-formed
Material: Tungsten Alloy



V_o vs Fragment Weight for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 70°

Fragment:
Type: B R L Pre-formed
Material: Tungsten Alloy



APPENDIX I

Tungsten Alloy Fragments vs Aluminum Alloy Plate

C. $(V_o)_W$ / $(V_o)_S$ vs Plate Thickness for Selected Obliquities

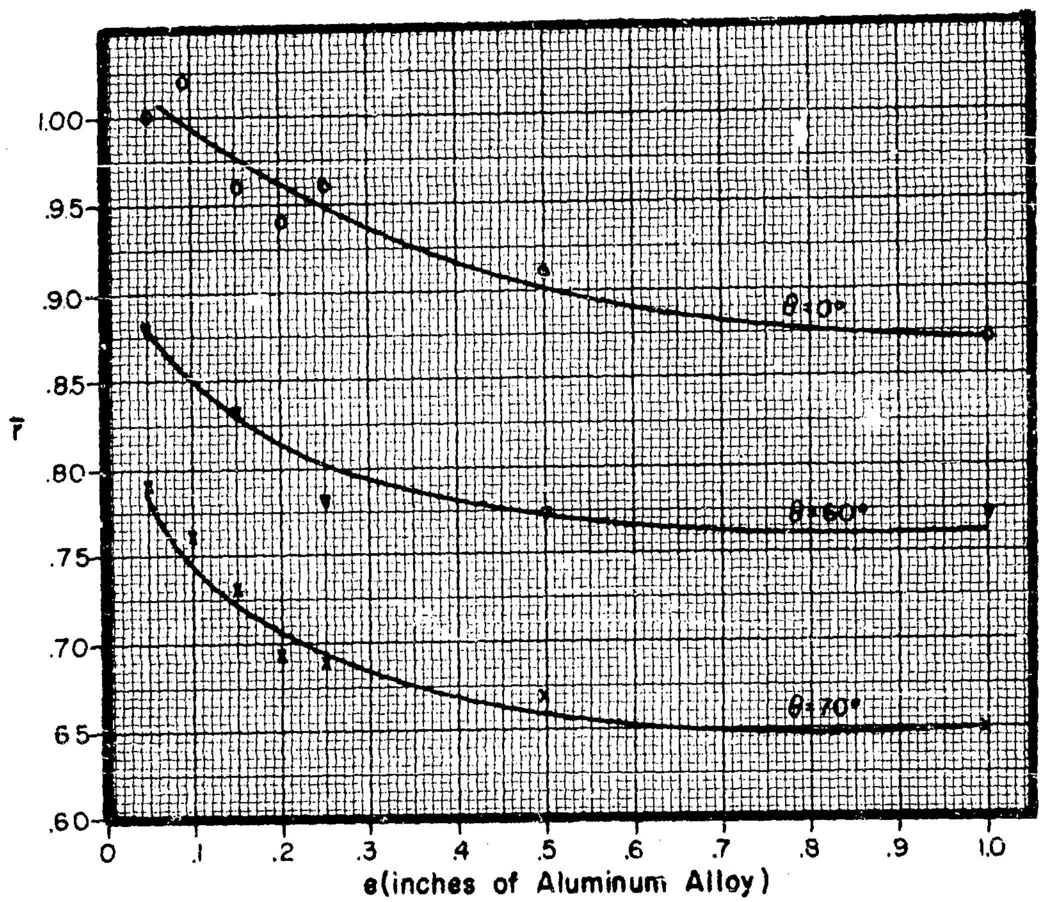
Comparison of Steel, Tungsten Fragments Impacting on Aluminum Alloy Plate

$\bar{r}$ vs e for Three Obliquities

NOTE: 1. $r = \frac{(V_o)_w}{(V_o)_s}$

2. $\bar{r}$ is the Average of the Values of r Corresponding to Selected Values of Fragment Weights for Any Given Set of Values of Obliquity and Material Thickness

3. Parameter Combinations Selected to Meet the Requirement that $(V_o)_s \geq$ 400 fps



APPENDIX I

Tungsten Alloy Fragments vs Aluminum Alloy Plate

D. $(V_r)_W$ / $(V_r)_S$ vs Plate Thickness for Selected Obliquities

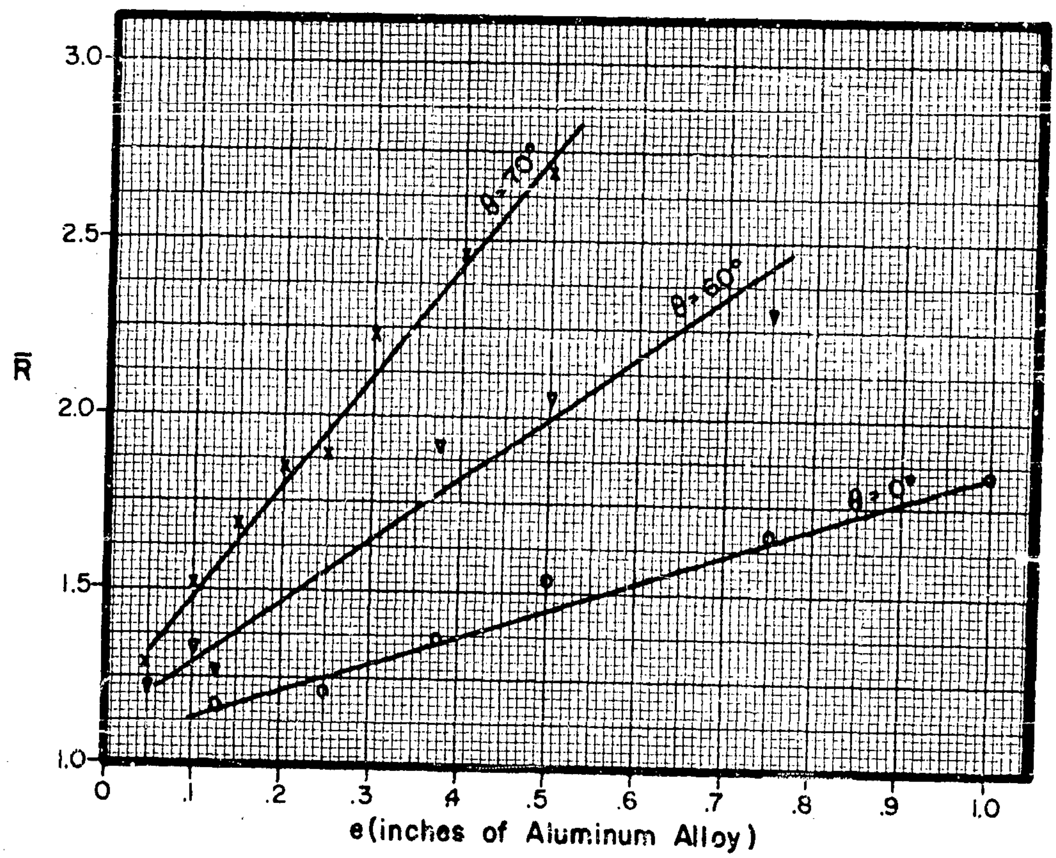
Comparison of Steel, Tungsten Fragments Impacting on Aluminum Alloy Plate

$\bar{R}$ vs e for Three Obliquit[illegible]

NOTE: 1. $R = \frac{(V_r)_w}{(V_r)_s}$

2. $\bar{R}$ is the Average of the Values of R for Various Fragment Weights and Striking Velocities; thus $\bar{R}$ Depends Only on e and θ

3. Parameter Combinations Selected to Meet the Requirement that $(V_r)_s \geq 1000$ fps



APPENDIX II

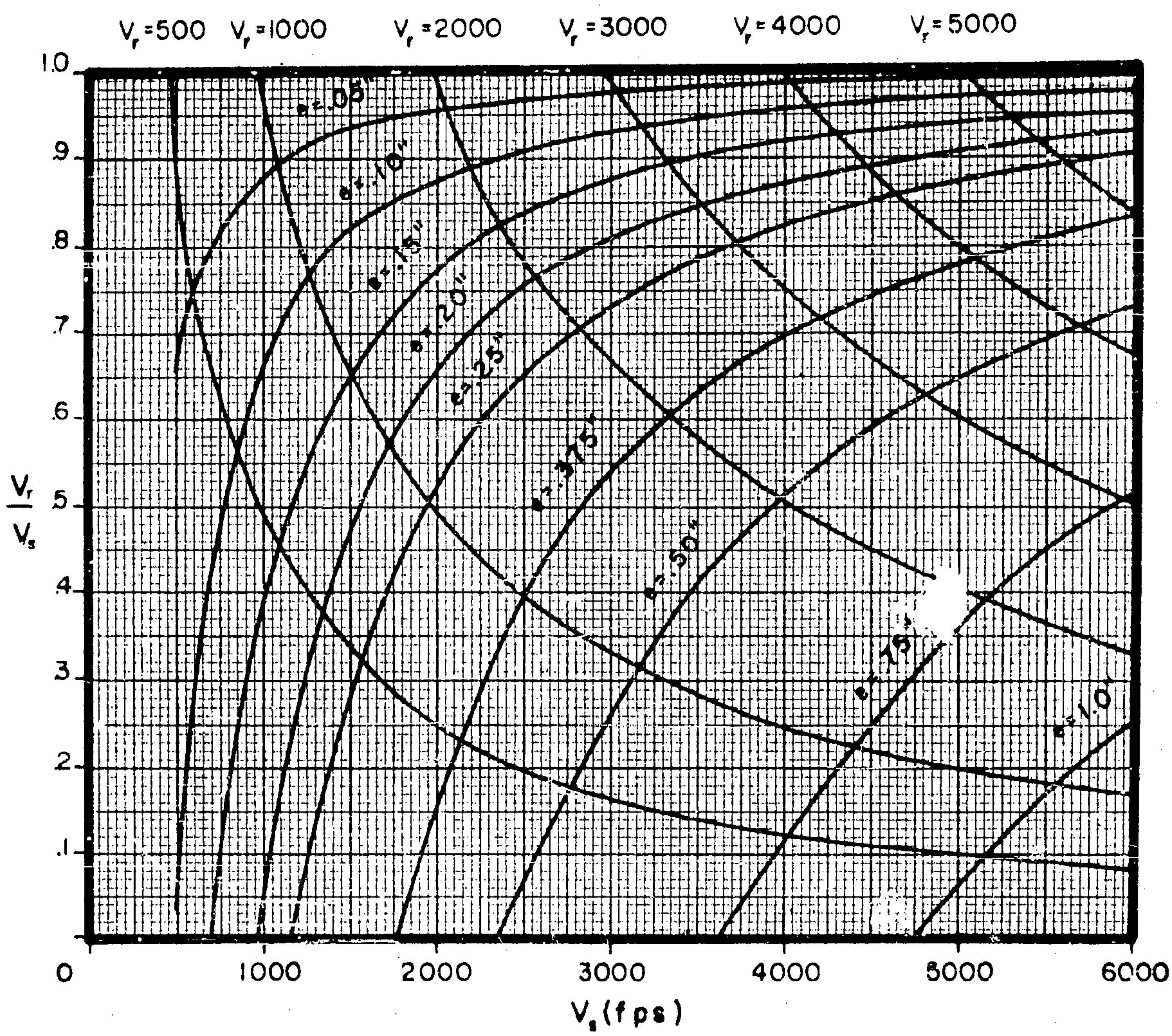
Uranium Fragments vs Aluminum Alloy Plate

A. Residual Velocity/Striking Velocity vs Striking Velocity for Selected Plate Thicknesses

$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 0°

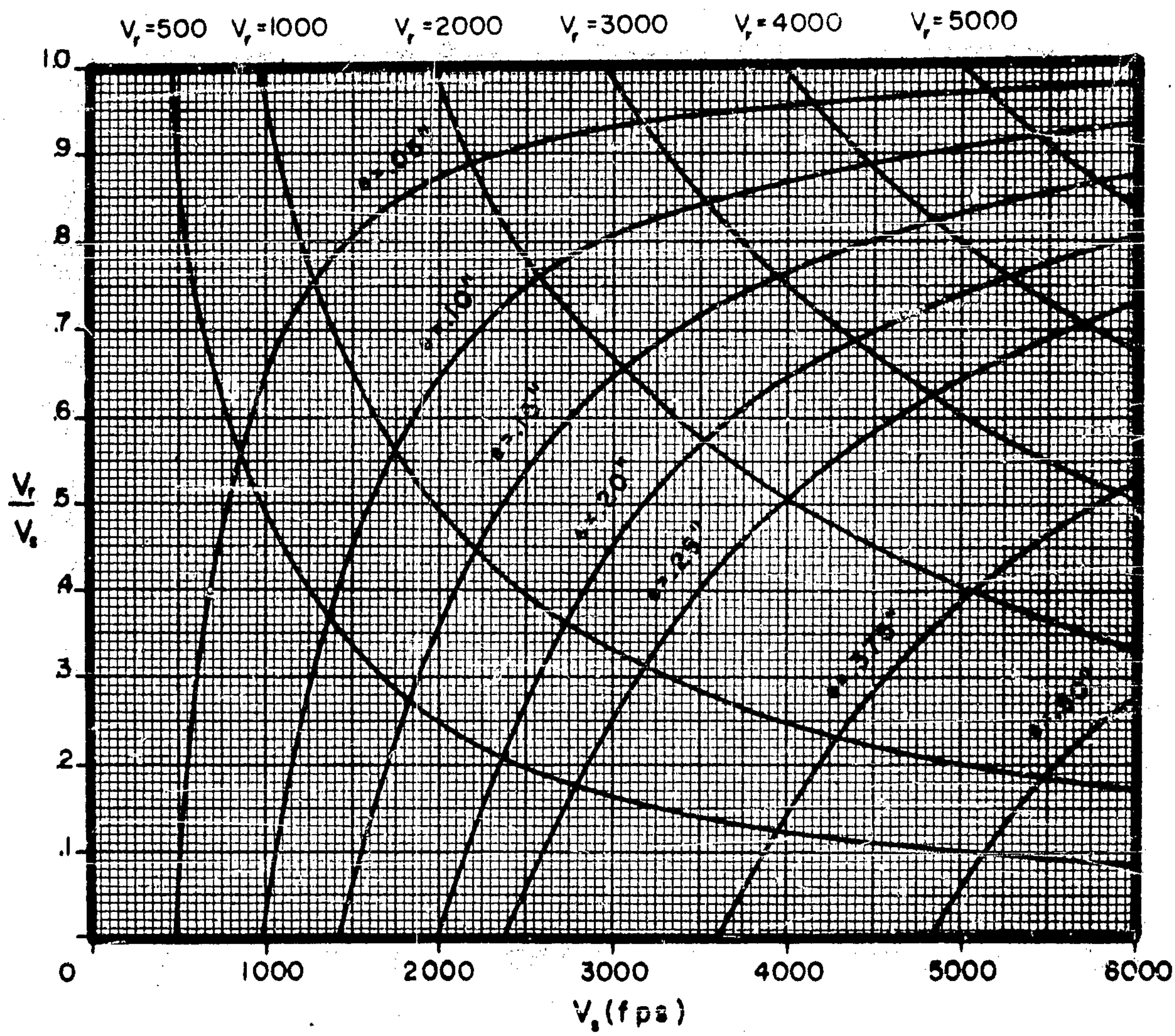
Fragment:
Type: BRL Pre-formed
Material: Uranium
Size: 30 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 60°

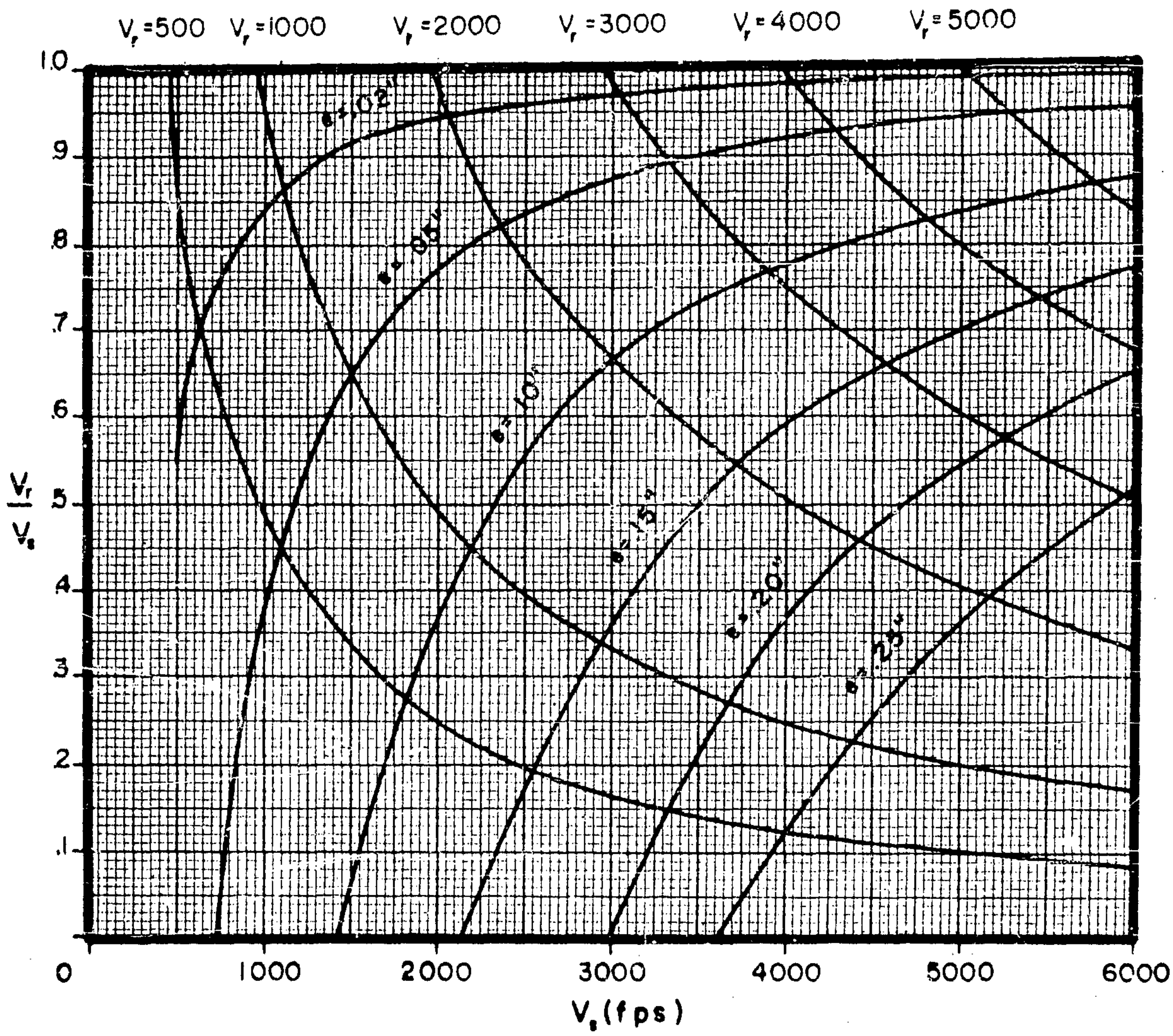
Fragment:
Type: BRL Pre-formed
Material: Uranium
Size: 30 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 70°

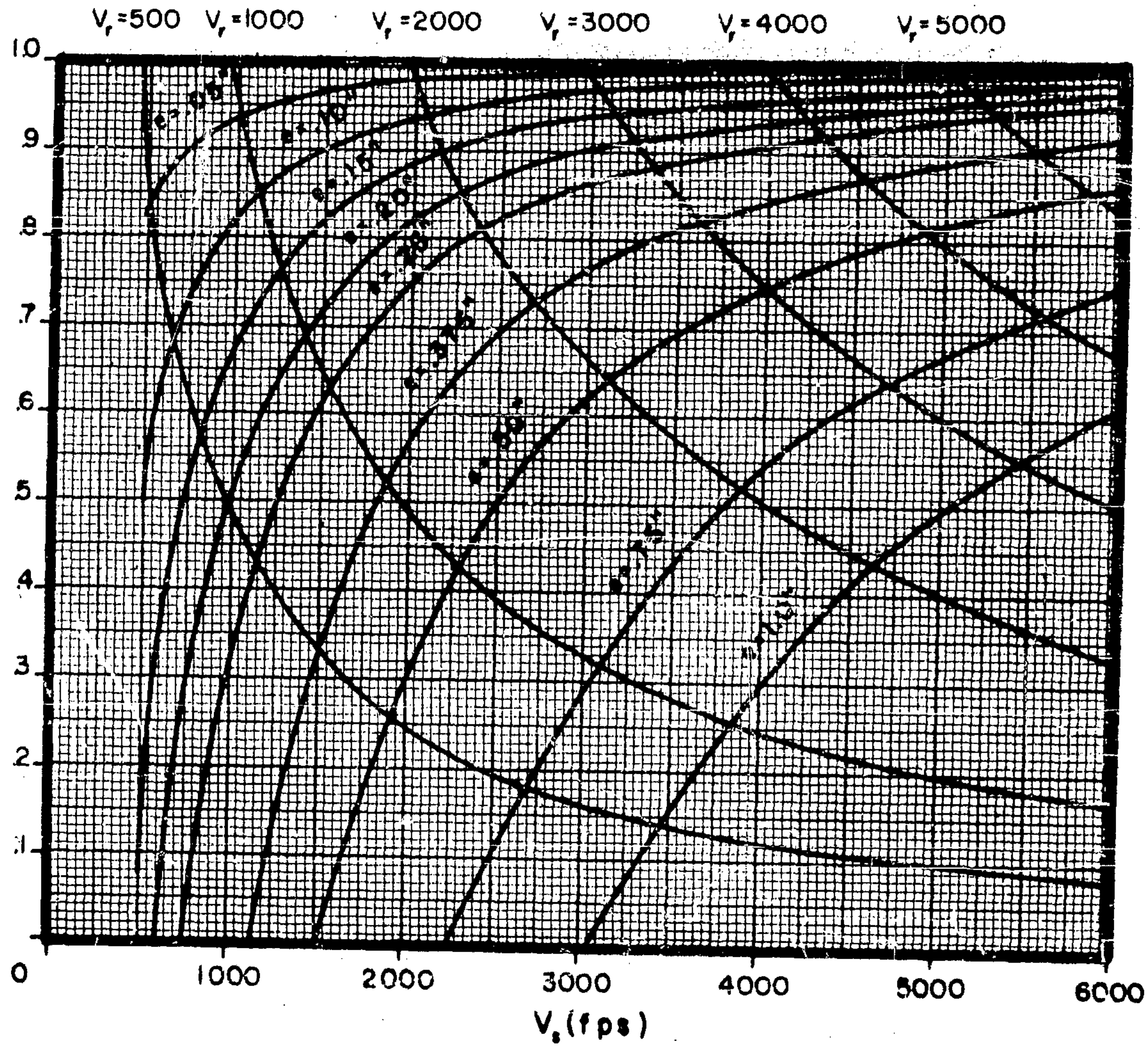
Fragment:
Type: BRL Pre-formed
Material: Uranium
Size: 30 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 0°

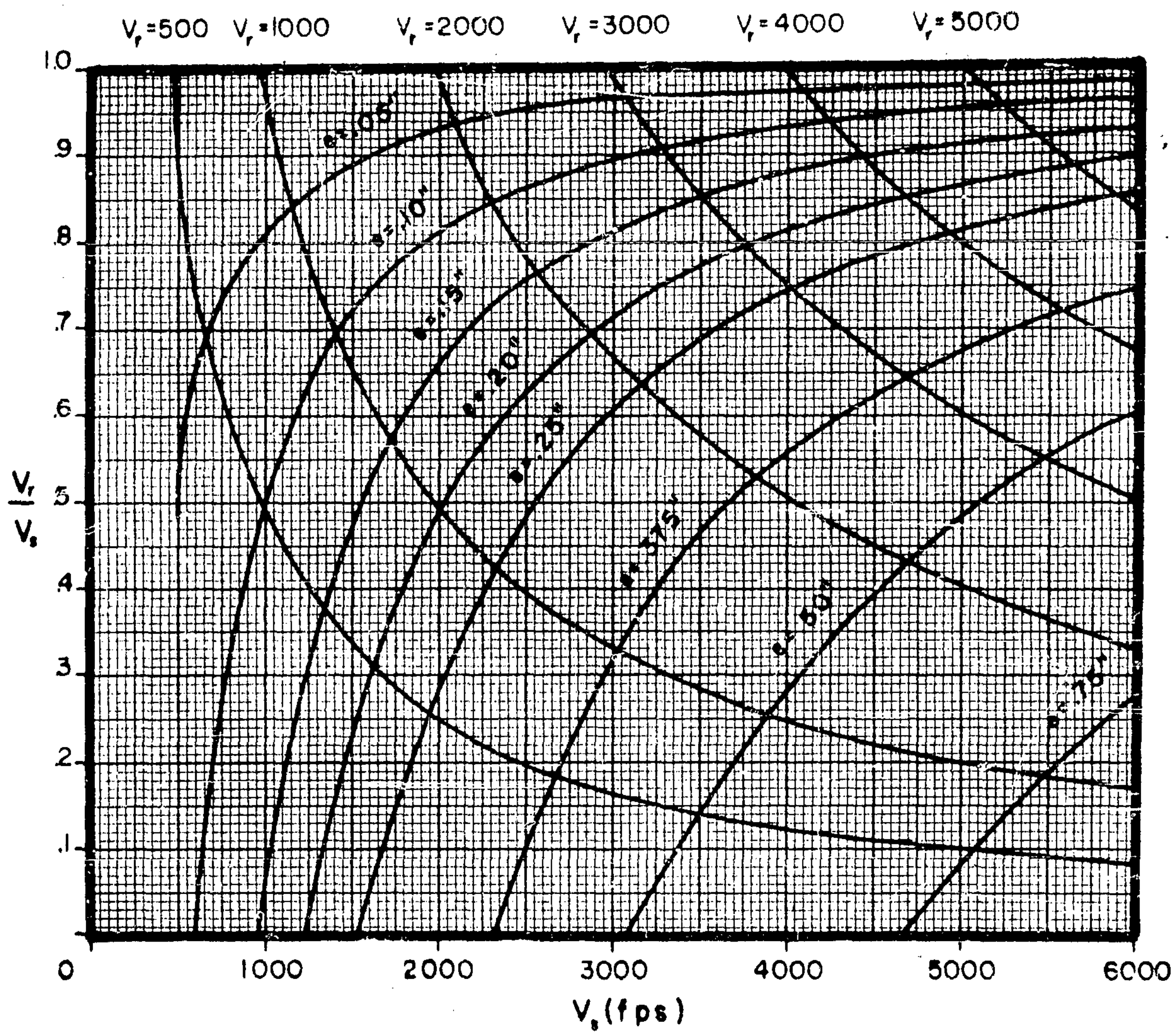
Fragment:
Type: BRL Pre-formed
Material: Uranium
Size: 100 grains



Residual Velocity / Striking Velocity vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 60°

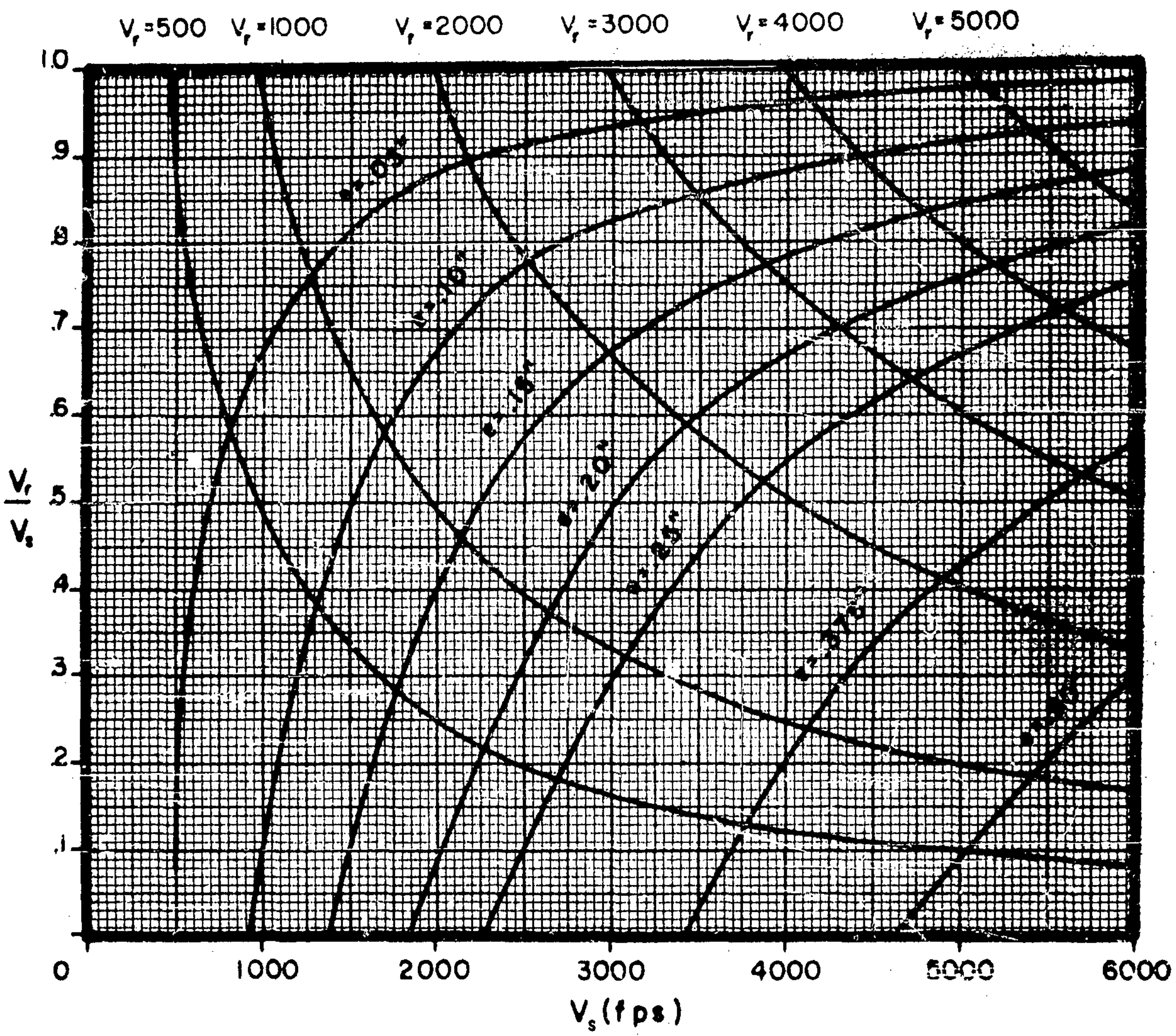
Fragment:
Type: BRL Pre-formed
Material: Uranium
Size: 100 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 70°

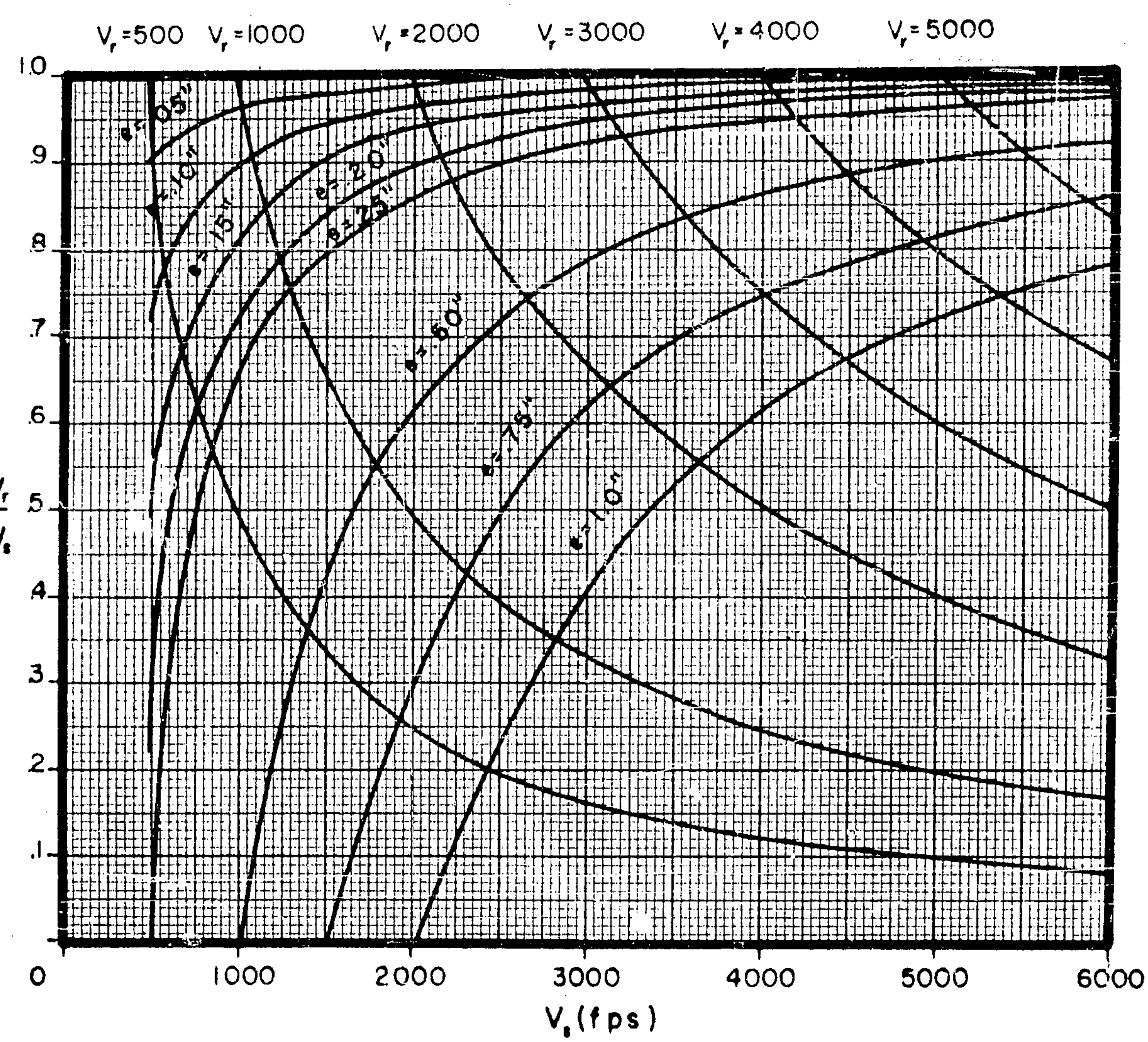
Fragment:
Type: BRL Pre-formed
Material: Uranium
Size: 100 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 0°

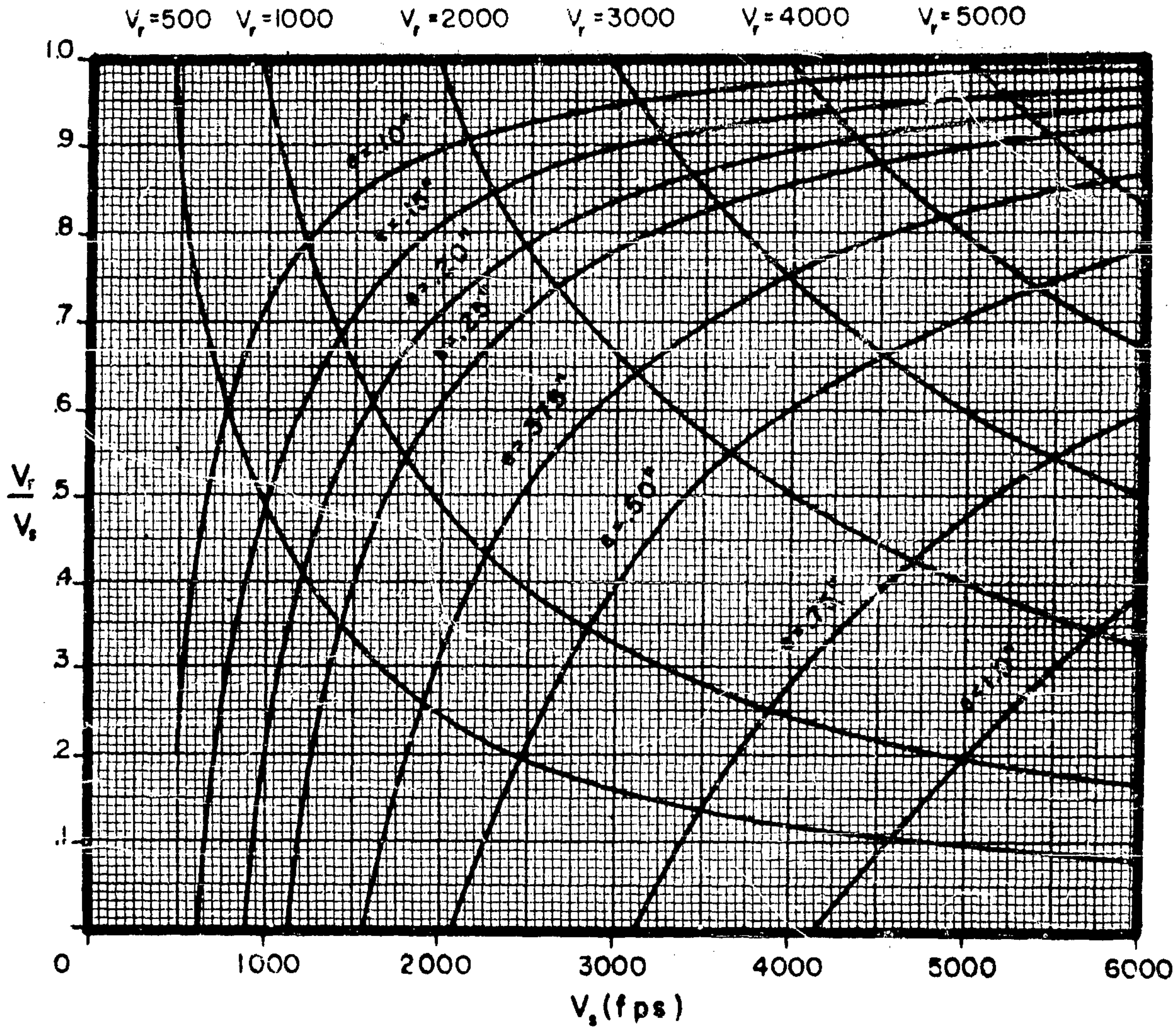
Fragment:
Type: BRL Pre-formed
Material: Uranium
Size: 300 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 60°

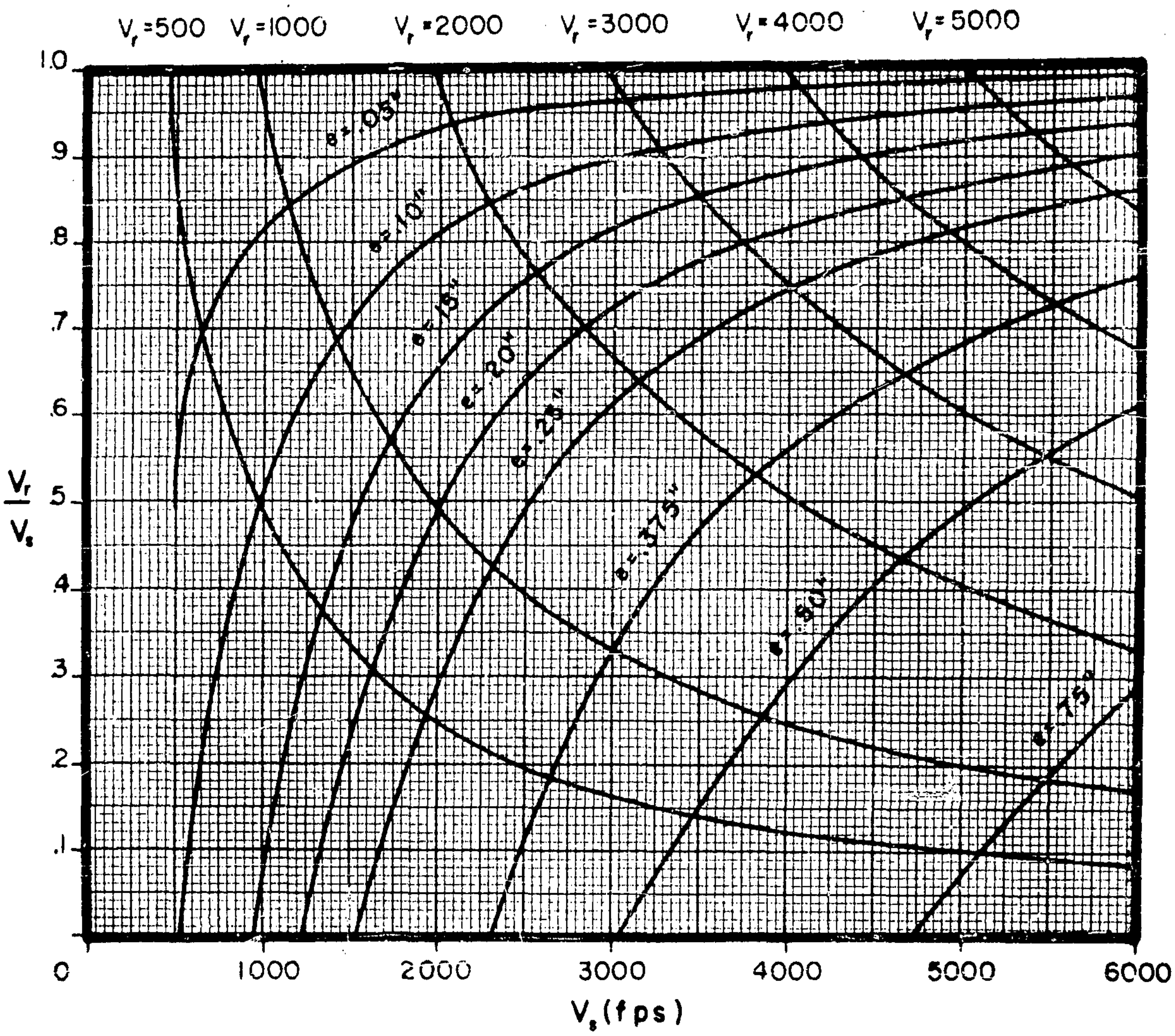
Fragment:
Type: BRL Pre-formed
Material: Uranium
Size: 300 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 70°

Fragment:
Type: BRL Pre-formed
Material: Uranium
Size: 300 grains



APPENDIX II

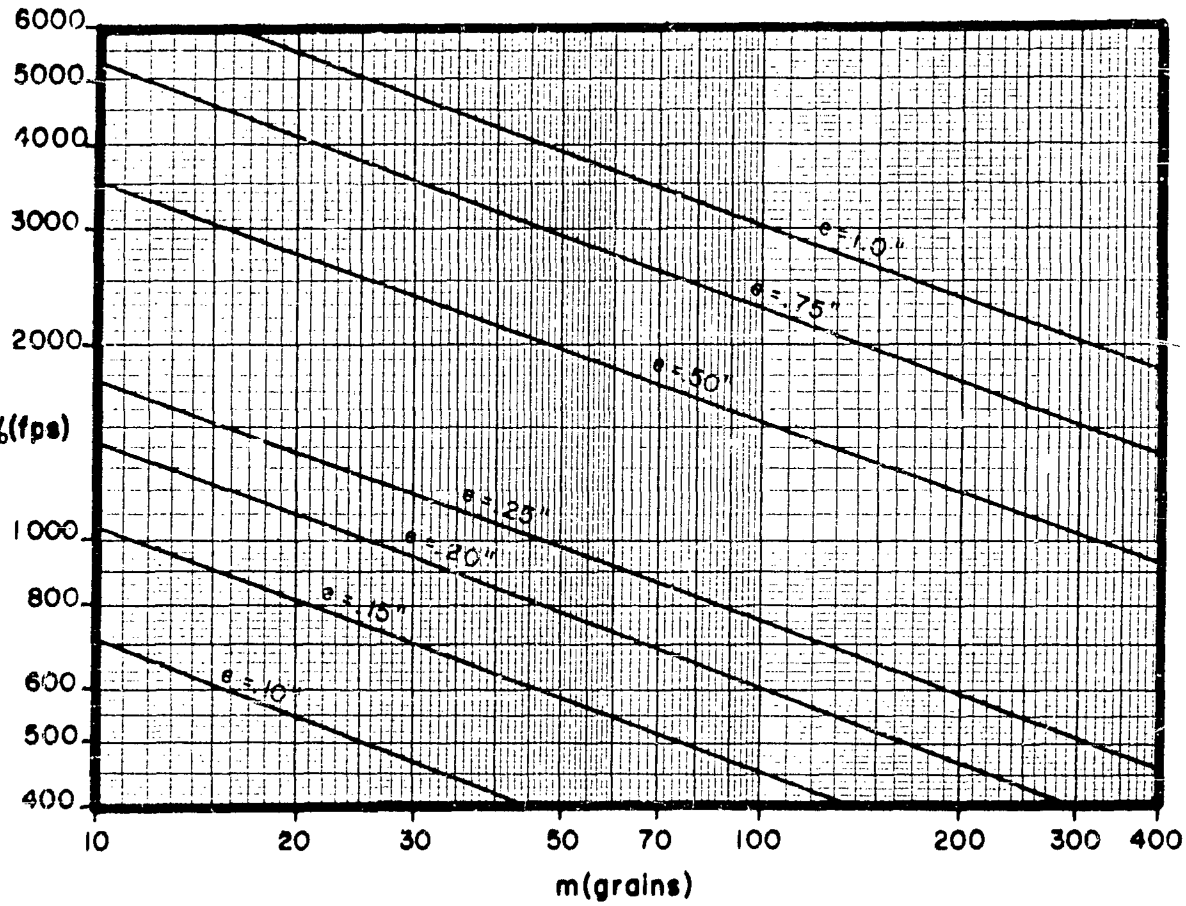
Uranium Fragments vs Aluminum Alloy Plate

B. V_o vs Fragment Weight for Selected Plate Thicknesses

V_o vs Fragment Weight for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 0°

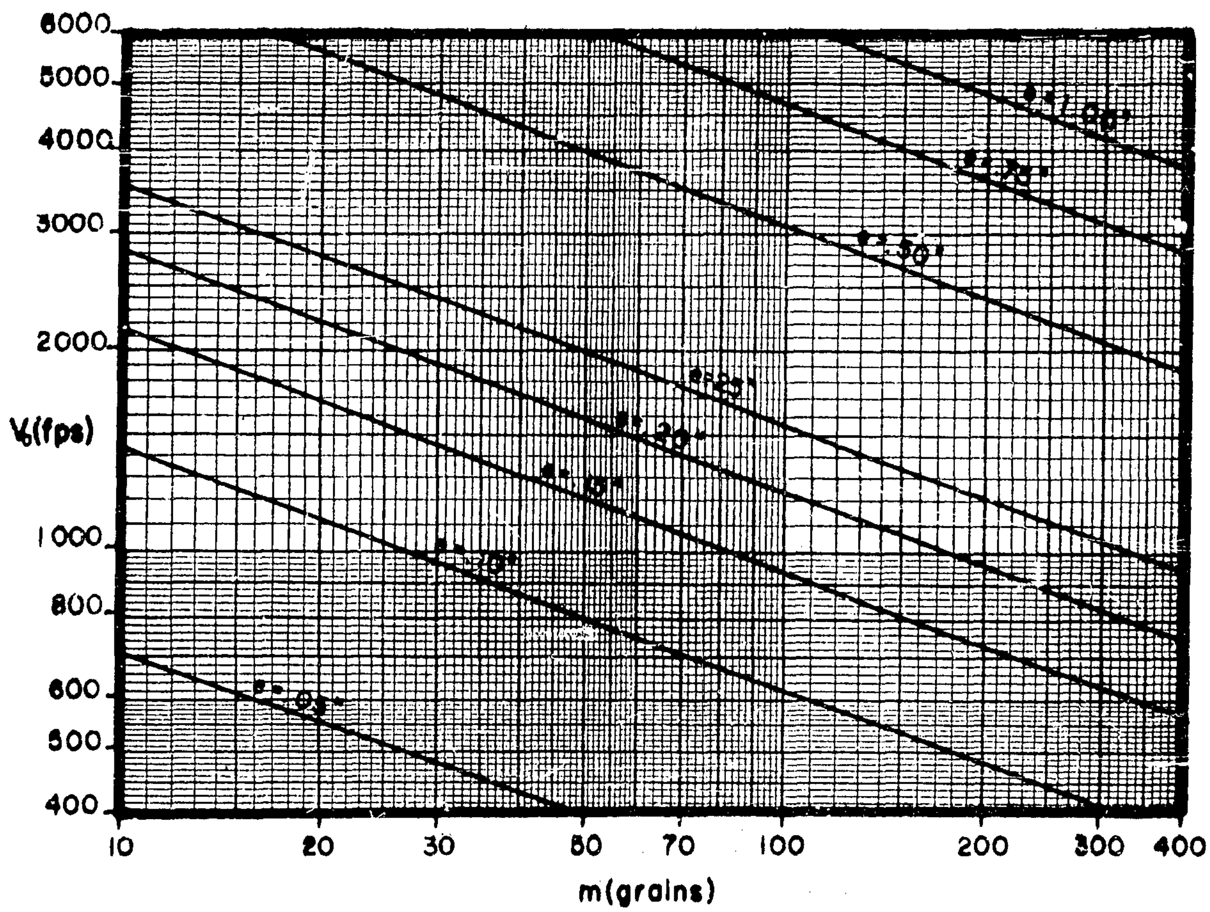
Fragment:
Type: B R L Pre-formed
Material: Uranium



V_o vs Fragment Weight for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 60°

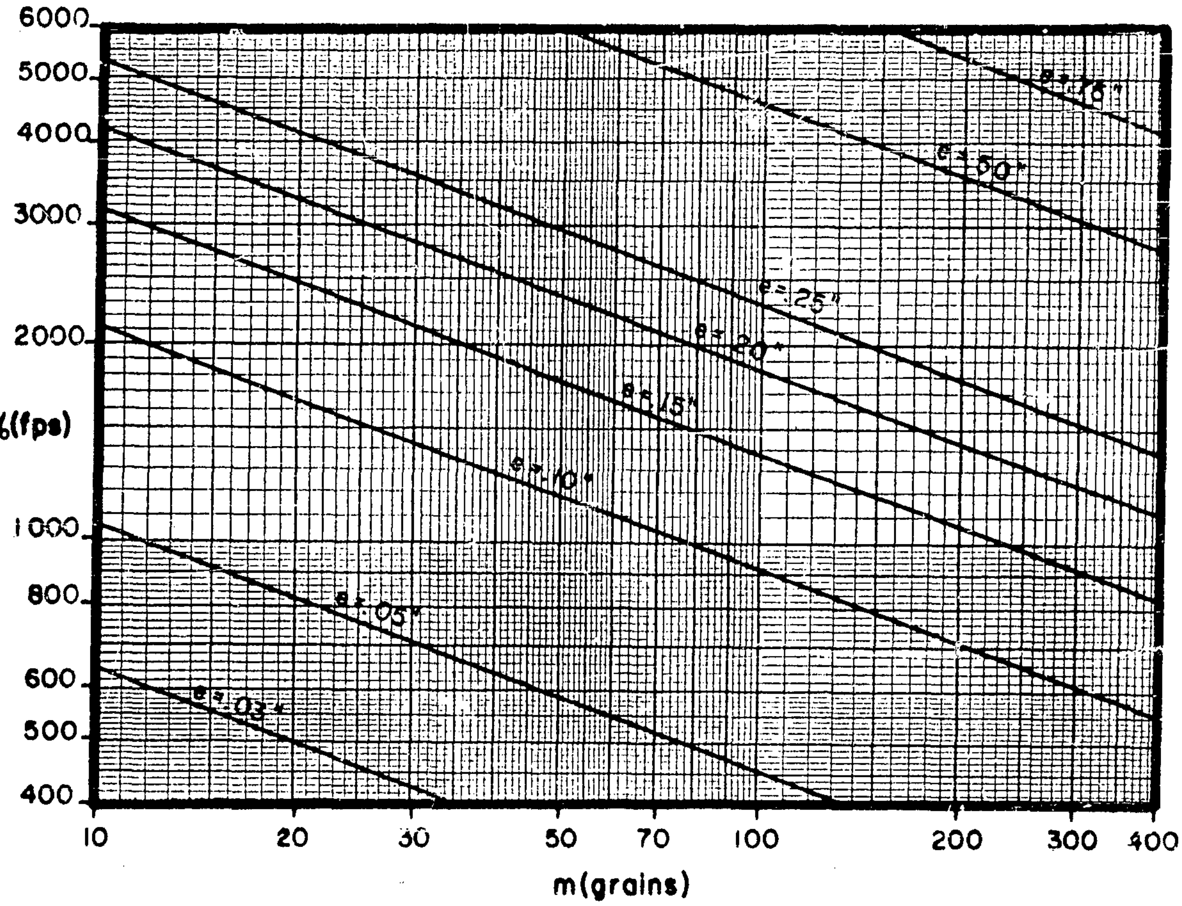
Fragment:
Type: B R L Pre-formed
Material: Uranium



V_o vs Fragment Weight for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 70°

Fragment:
Type: B R L Pre-formed
Material: Uranium



APPENDIX II

Uranium Fragments vs Aluminum Alloy Plate

C. $(V_o)_U$ / $(V_o)_S$ vs Plate Thickness for Selected Obliquities

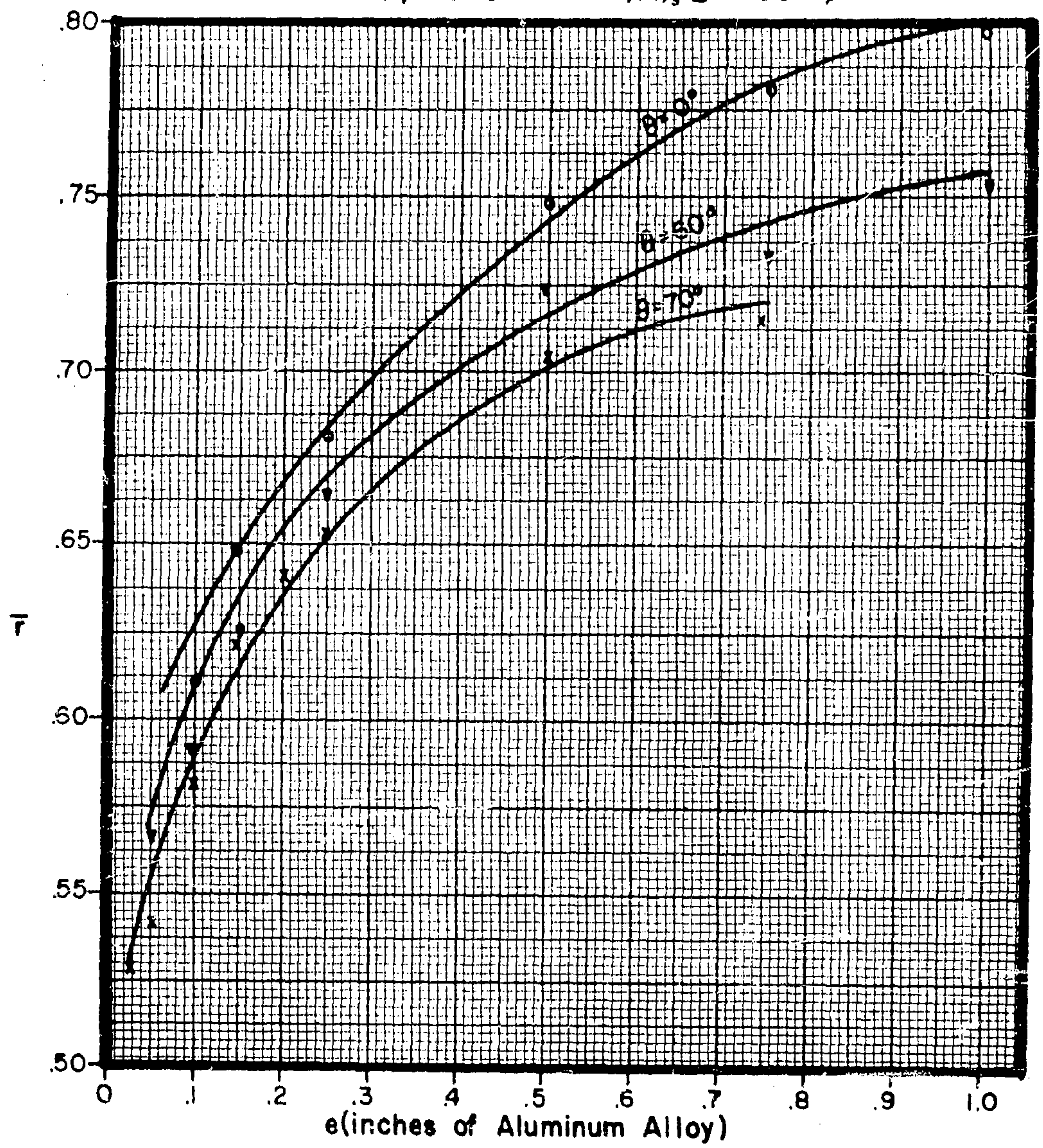
Comparison of Steel, Uranium Fragments Impacting on Aluminum Alloy Plate

$\bar{r}$ vs e for Three Obliquities

NOTE: 1. $r = \frac{(V_o)_u}{(V_o)_s}$

2. $\bar{r}$ is the Average of the Values of r Corresponding to Selected Values of Fragment Weights for Any Given Set of Values of Obliquity and Material Thickness

3. Parameter Combinations Selected to Meet the Requirement that $(V_o)_s \geq$ 400 fps



APPENDIX II

Uranium Fragments vs Aluminum Alloy Plate

D. $(V_r)_U$ / $(V_r)_S$ vs Plate Thickness for Selected Obliquities

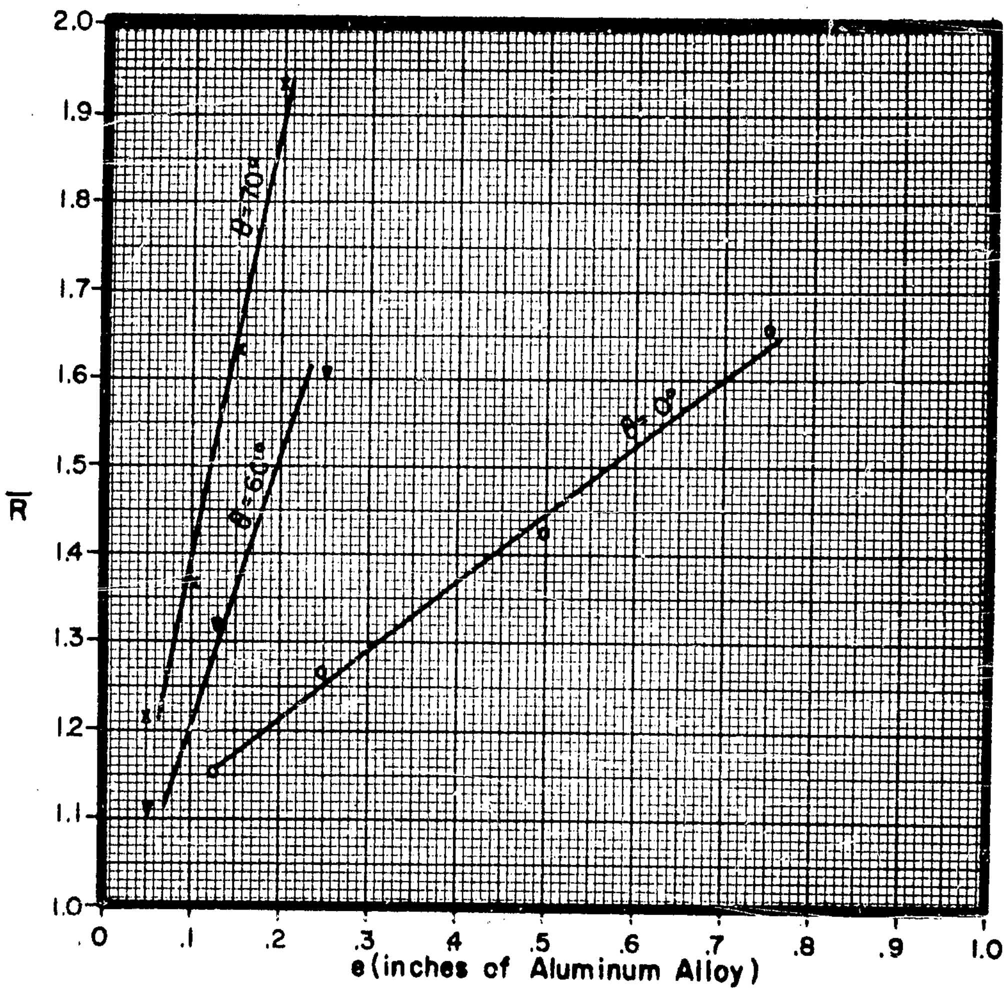
Comparison of Steel, Uranium Fragments Impacting on Aluminum Alloy Plate

$\overline{R}$ vs e for Three Obliquities

NOTE: 1. $R = \frac{(V_r)_u}{(V_r)_s}$

2. $\overline{R}$ is the Average of the Values of R for Various Fragment Weights and Striking Velocities; thus $\overline{R}$ Depends Only on e and θ

3. Parameter Combinations Selected to Meet the Requirement that $(V_r)_s \geq 1000$ fps



APPENDIX III

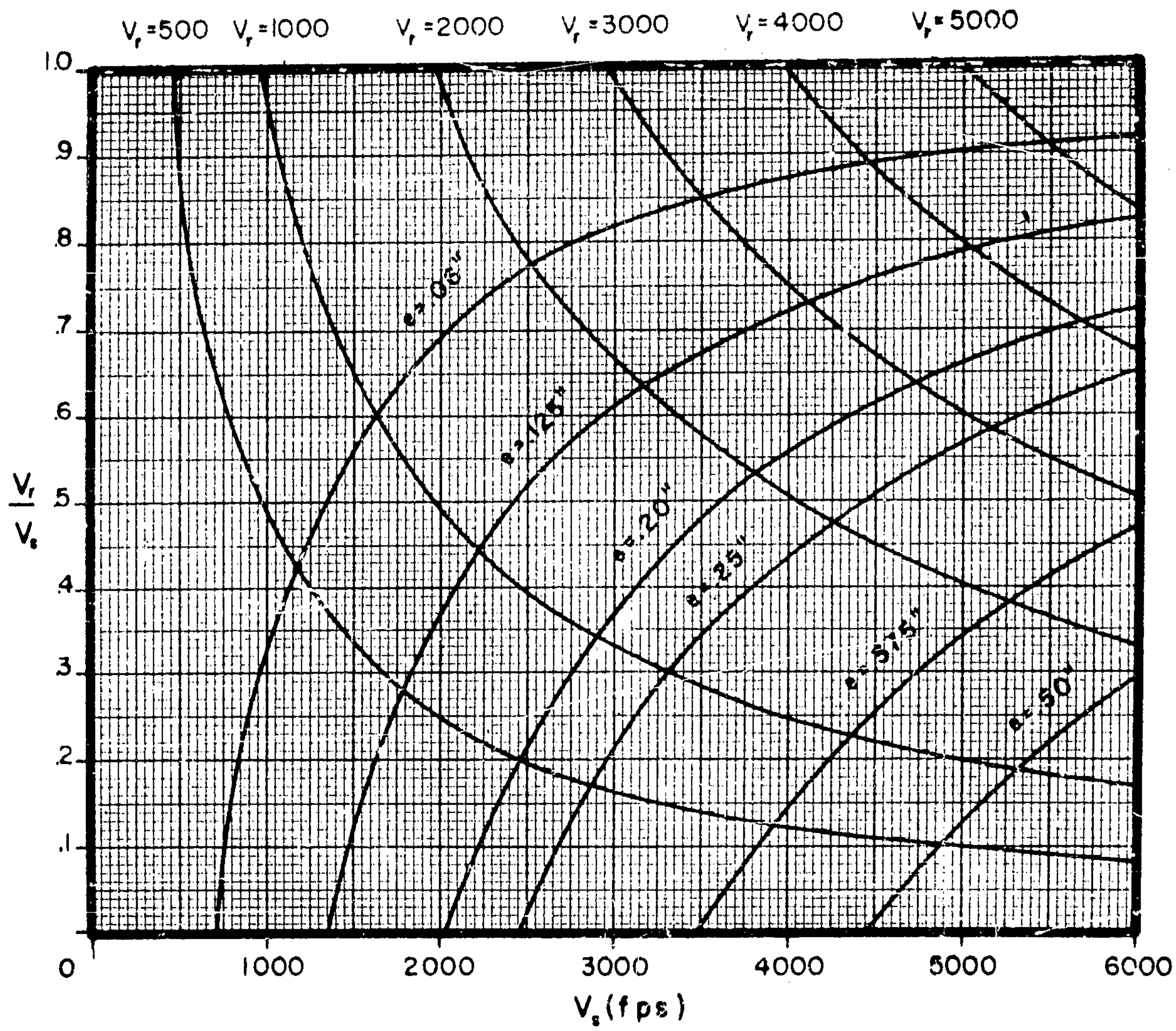
Aluminum Alloy Fragments vs Aluminum Alloy Plate

A. Residual Velocity/Striking Velocity vs Striking Velocity for Selected Plate Thicknesses

$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 0°

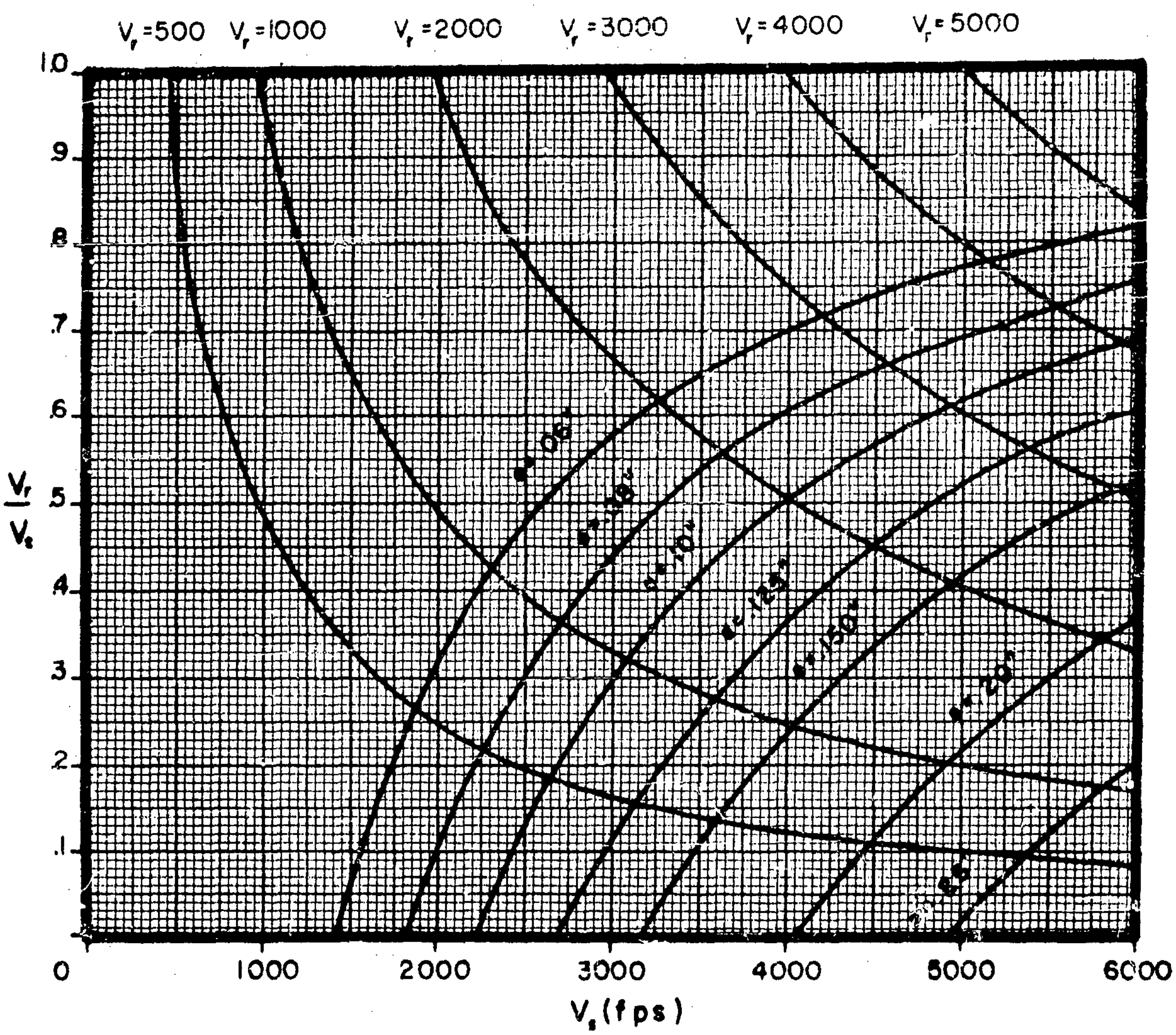
Fragment:
Type: BRL Pre-formed
Material: Aluminum Alloy
Size: 30 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 60°

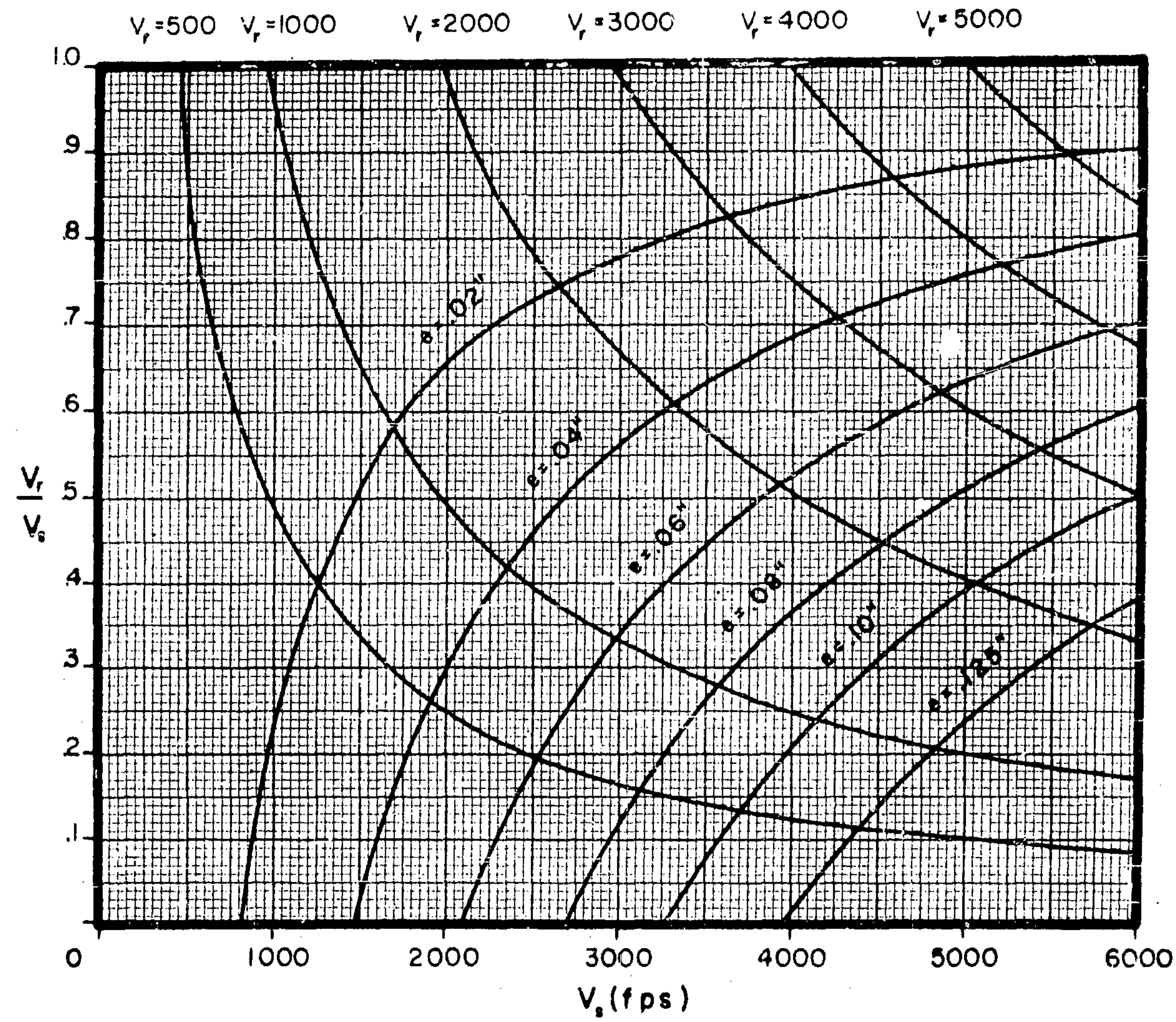
Fragment:
Type: BRL Pre-formed
Material: Aluminum Alloy
Size: 30 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 70°

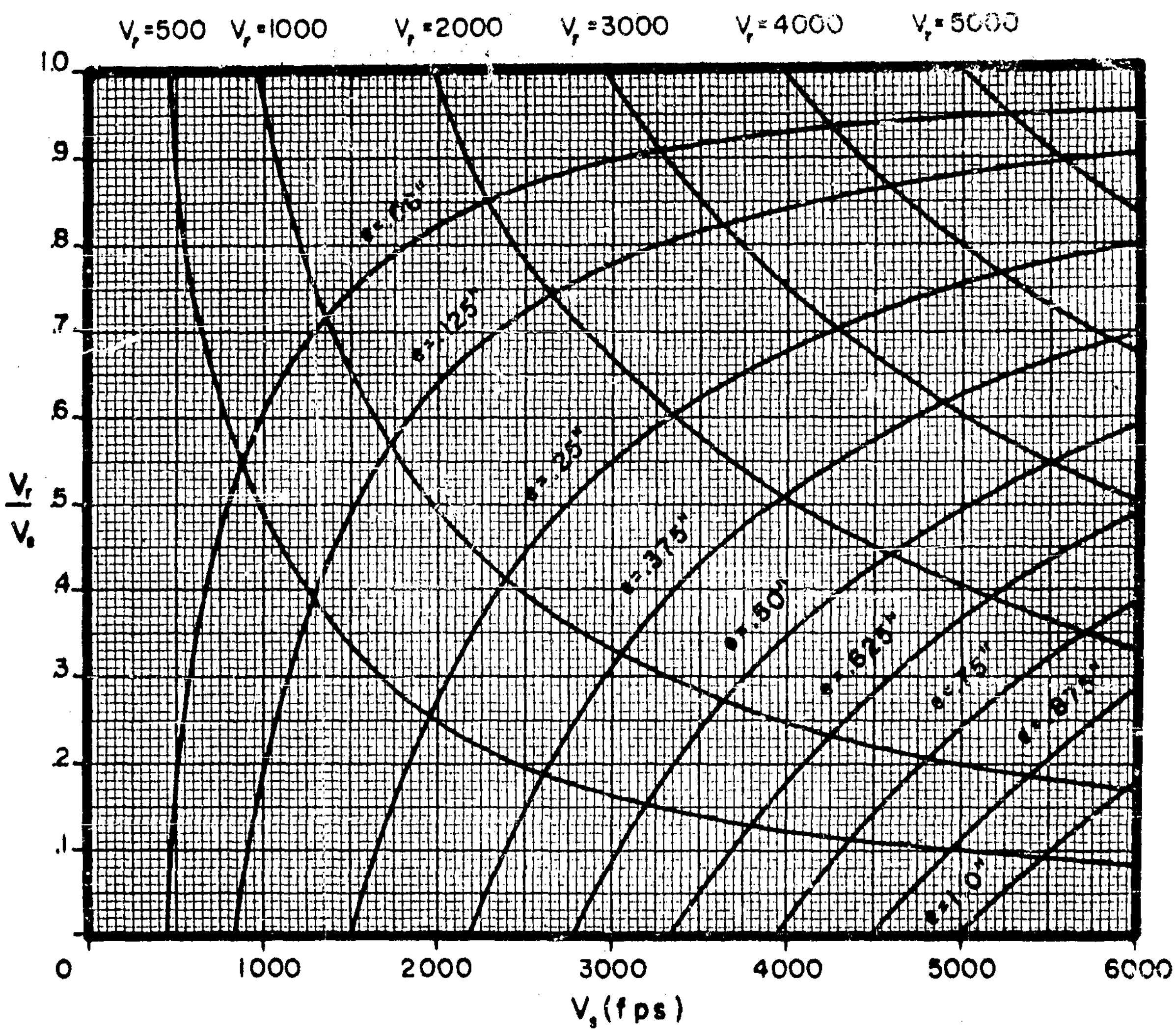
Fragment:
Type: BRL Pre-formed
Material: Aluminum Alloy
Size: 30 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 0°

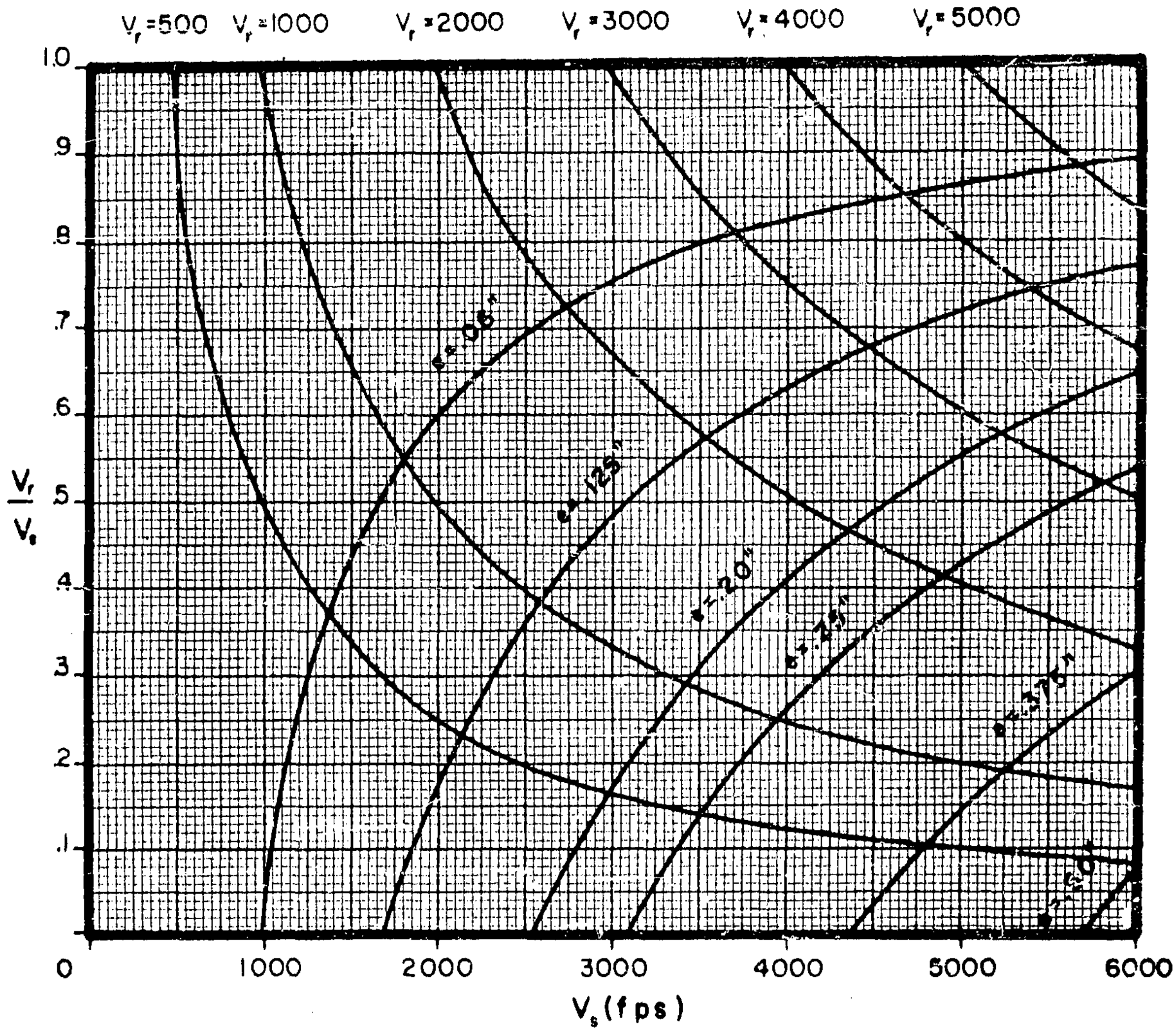
Fragment:
Type: BRL Pre-formed
Material: Aluminum Alloy
Size: 100 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 60°

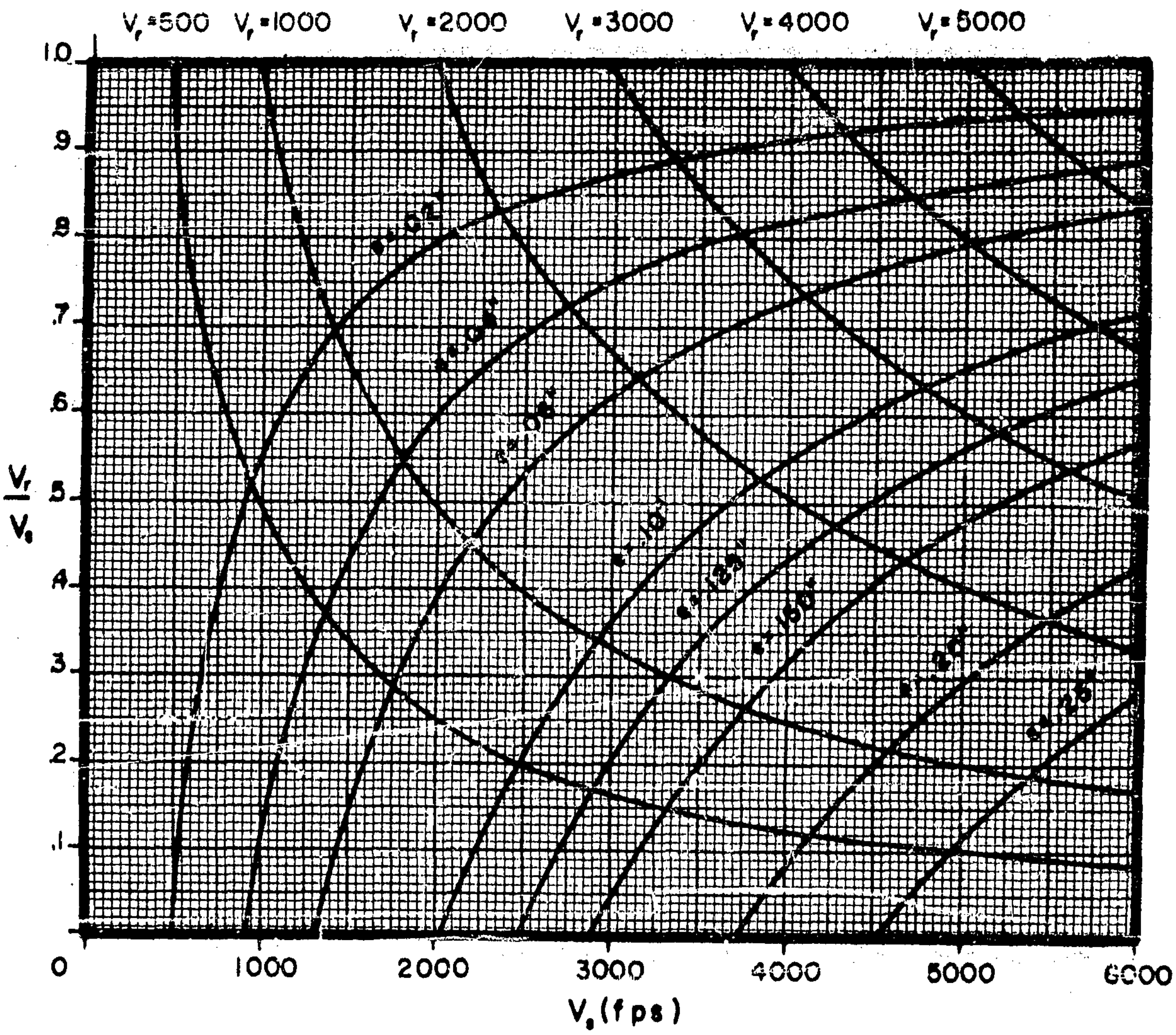
Fragment:
Type: BRL Pre-formed
Material: Aluminum Alloy
Size: 100 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 70°

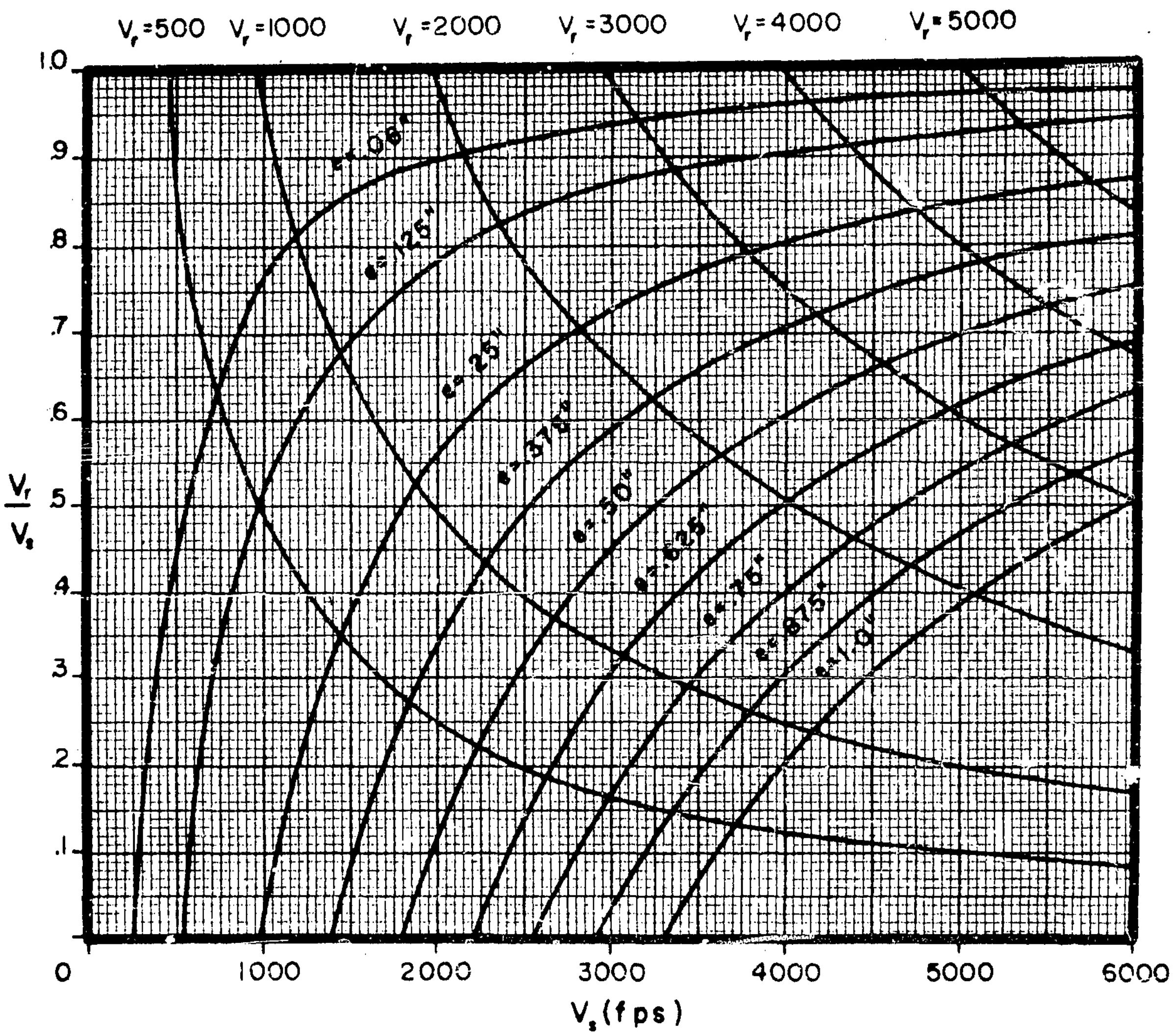
Fragment:
Type: BRL Pre-formed
Material: Aluminum Alloy
Size: 100 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 0°

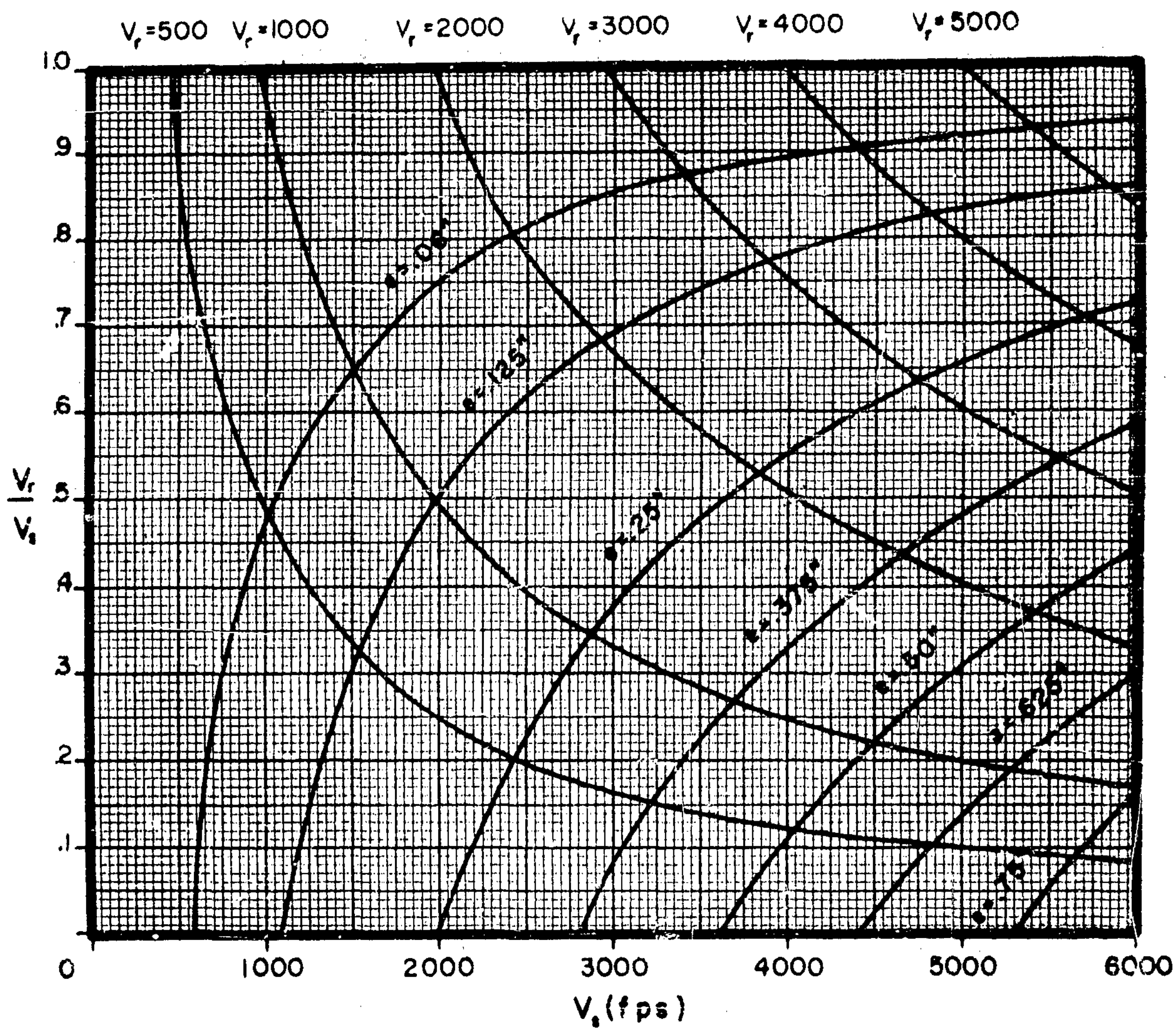
Fragment:
Type: BRL Pre-formed
Material: Aluminum Alloy
Size: 300 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 60°

Fragment:
Type: BRL Pre-formed
Material: Aluminum Alloy
Size: 300 grains

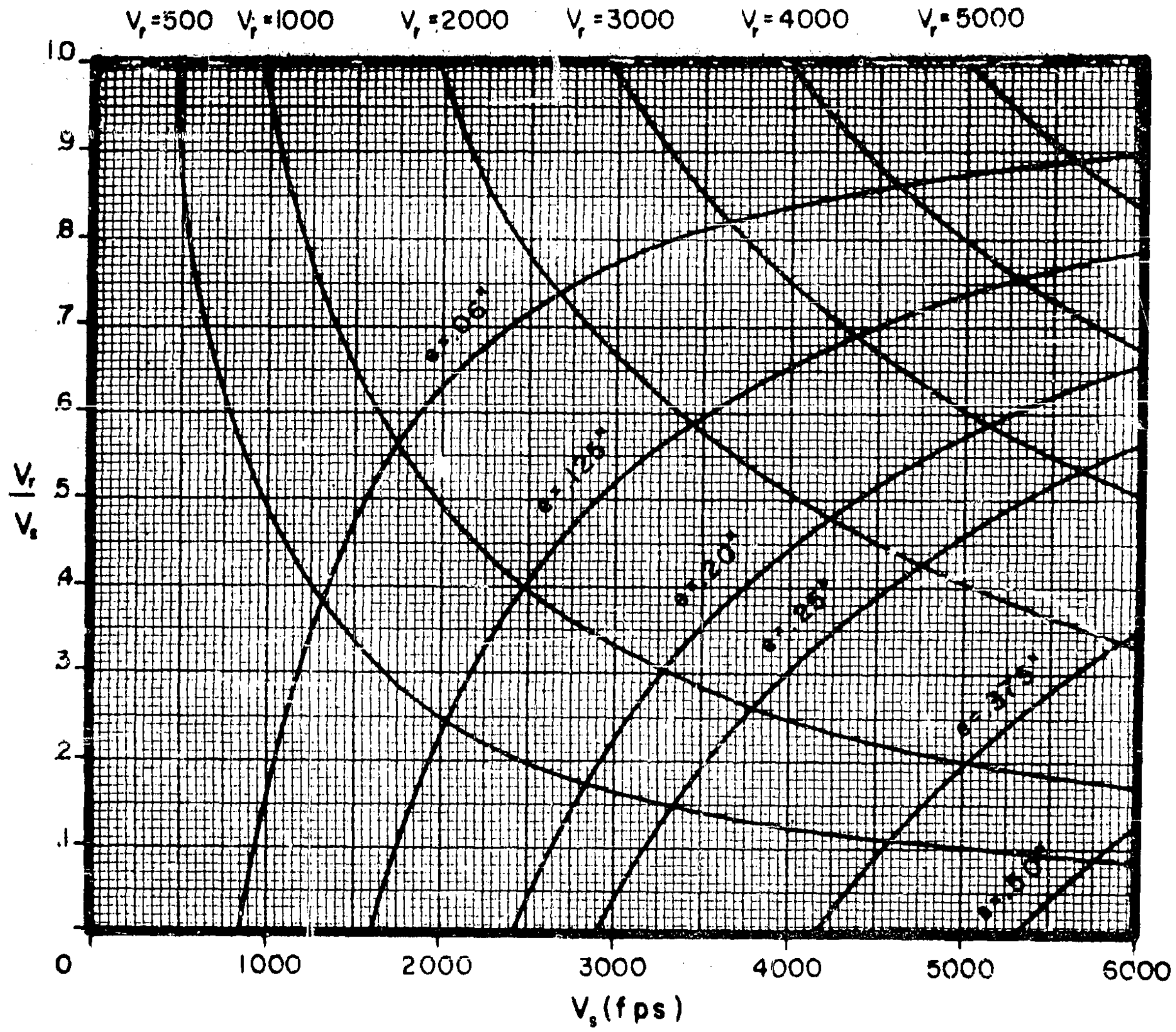


CONFIDENTIAL

$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 70°

Fragment:
Type: BRL Pre-formed
Material: Aluminum Alloy
Size: 300 grains



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APPENDIX [illegible]

Aluminum Alloy Fragments vs Aluminum Alloy Plate

B. V_o vs Fragment Weight for Selected Plate Thicknesses

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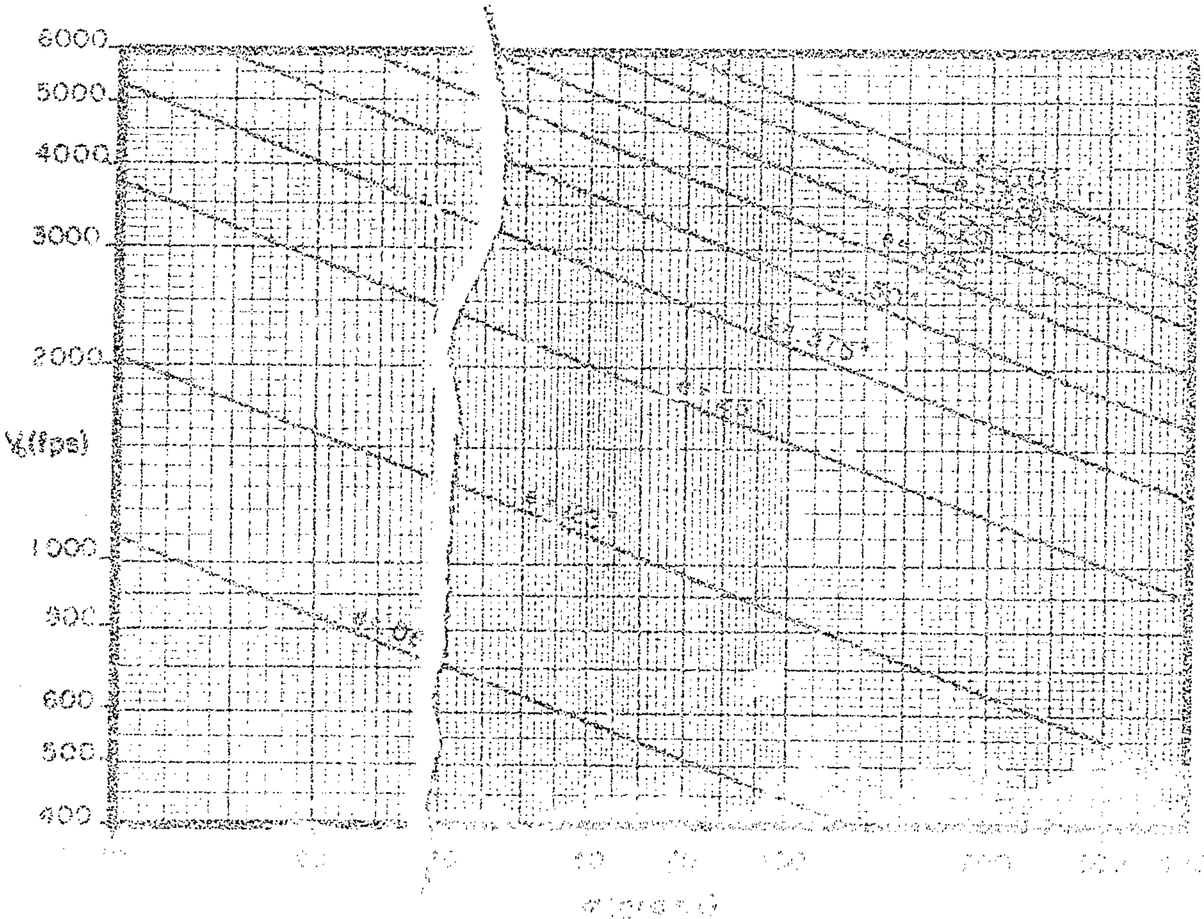

6000
5000
4000
3000
2000
V(fps)
1000
600
500
400

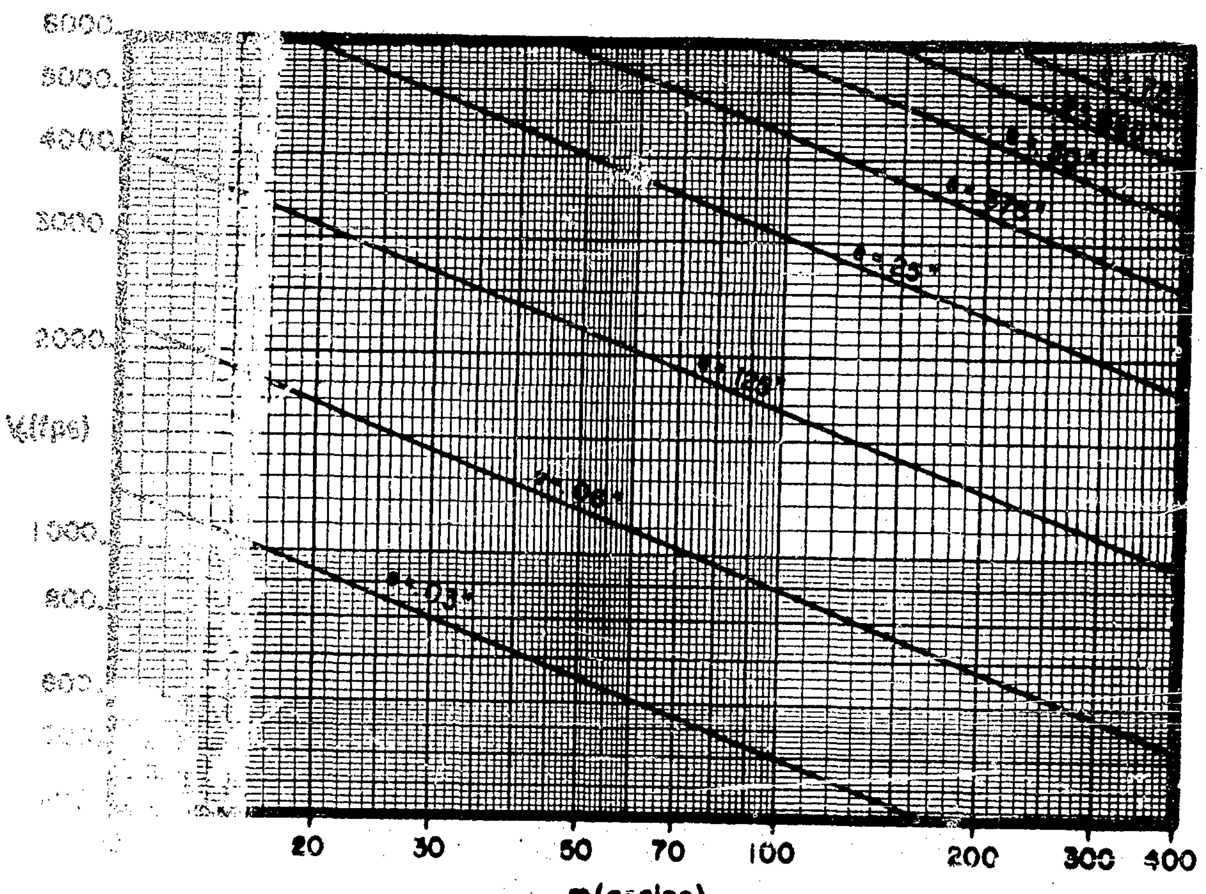
V_o vs Fragment Weight
Selected Plate Thicknesses

Aluminum Alloy

Fragment:

Type: B R L Pre-formed

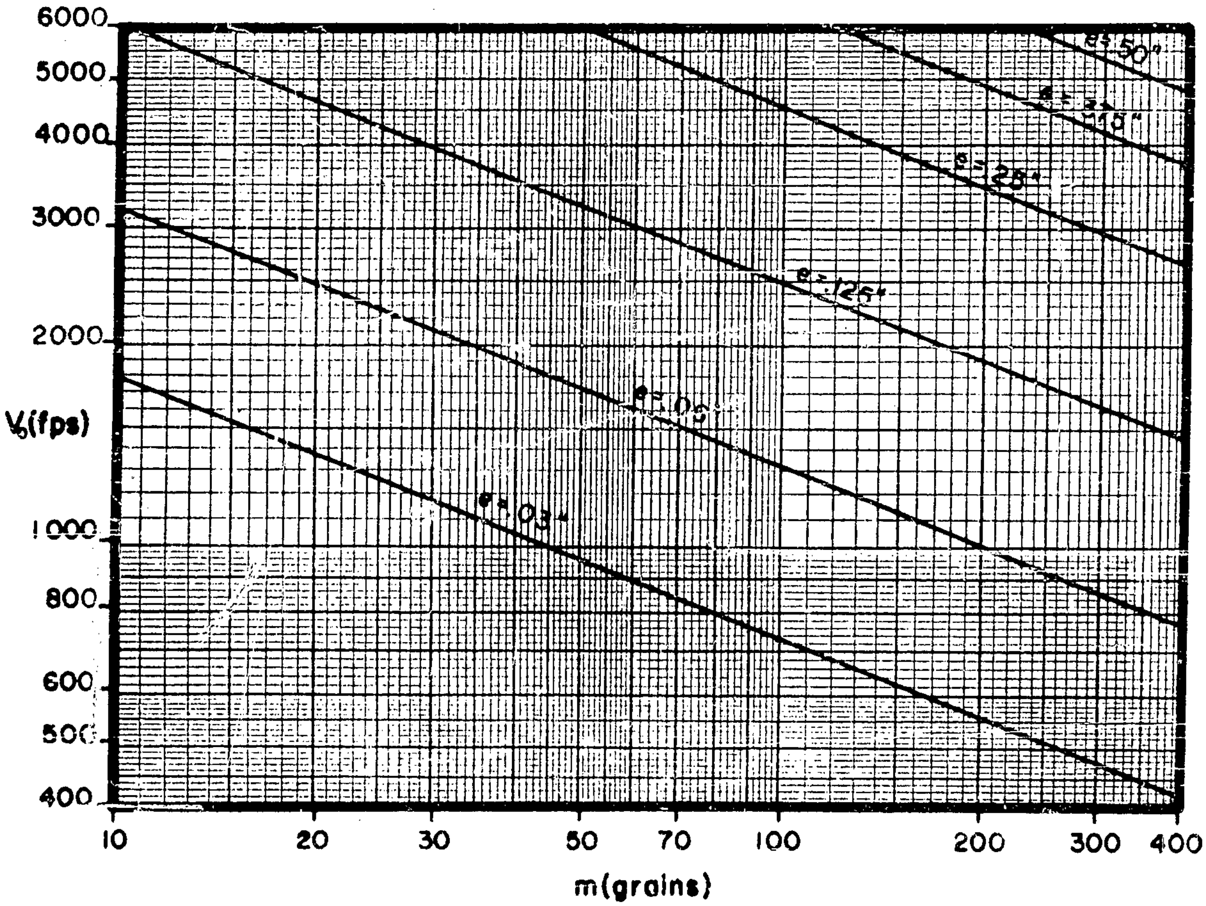
Material: Aluminum Alloy



V_o vs Fragment Weight for Selected Plate Thicknesses

Plate Material: Aluminum Alloy
Obliquity: 70°

Fragment:
Type: B R L Pre-formed
Material: Aluminum Alloy



APPENDIX III

Aluminum Alloy Fragments vs Aluminum Alloy Plate

C. $(V_o)_{AA}$ / $(V_o)_S$ vs Plate Thickness for Selected Obliquities

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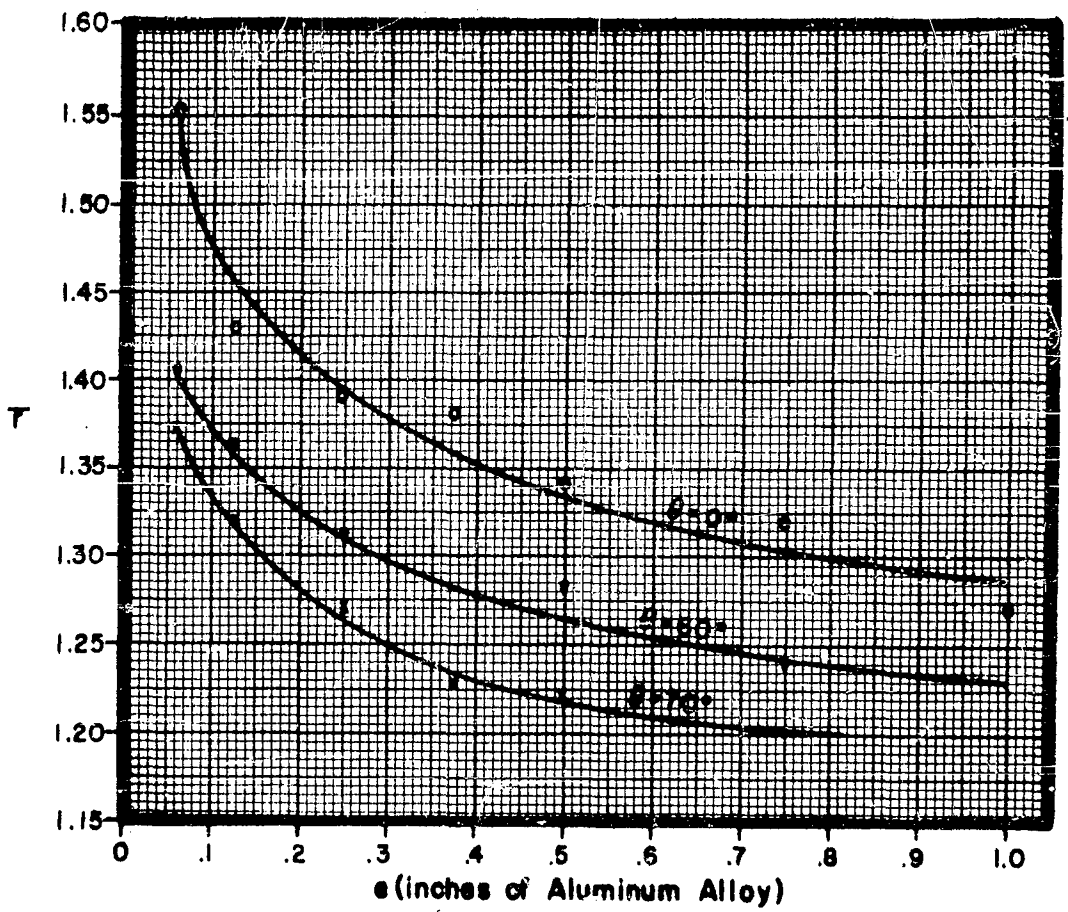
Comparison of Steel, Aluminum Alloy Fragments Impacting on Aluminum Alloy Plate

$\bar{r}$ vs e for Three Obliquities

NOTE: 1. $r = \frac{(V_o)_{AA}}{(V_o)_S}$

2. $\bar{r}$ is the Average of the Values of r Corresponding to Selected Values of Fragment Weights for Any Given Set of Values of Obliquity and Material Thickness

3. Parameter Combinations Selected to Meet the Requirement that $(V_o)_S \geq 400$ fps



CONFIDENTIAL

APPENDIX III

Aluminum Alloy Fragments vs Aluminum Alloy Plate

D. $(V_r)_{AA}$ / $(V_r)_S$ vs Plate Thickness for Selected Obliquities

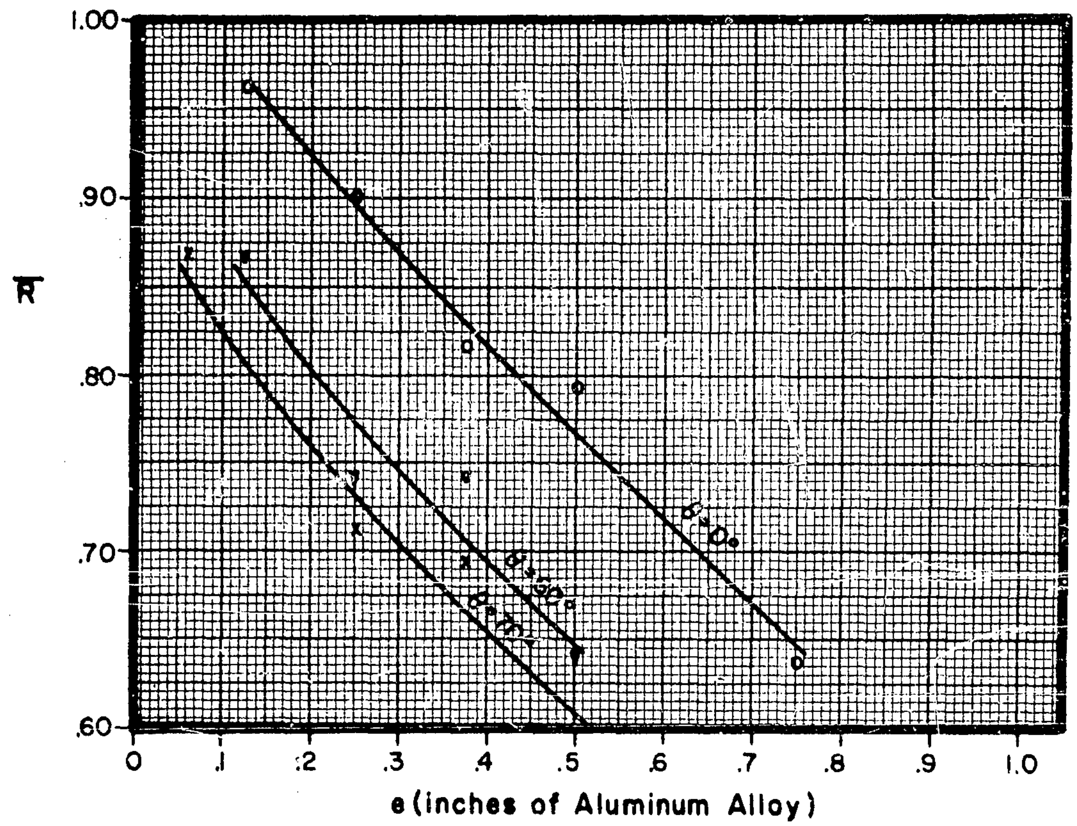
Comparison of Steel, Aluminum Alloy Fragments Impacting on Aluminum Alloy Plate

$\bar{R}$ vs e for Three Obliquities

NOTE: 1. $R = \frac{(V_r)_{AA}}{(V_r)_S}$

2. $\bar{R}$ is the Average of the Values of R for Various Fragment Weights and Striking Velocities; thus $\bar{R}$ Depends Only on e and θ

3. Parameter Combinations Selected to Meet the Requirement that $(V_r)_S \geq 1000$ fps



APPENDIX IV

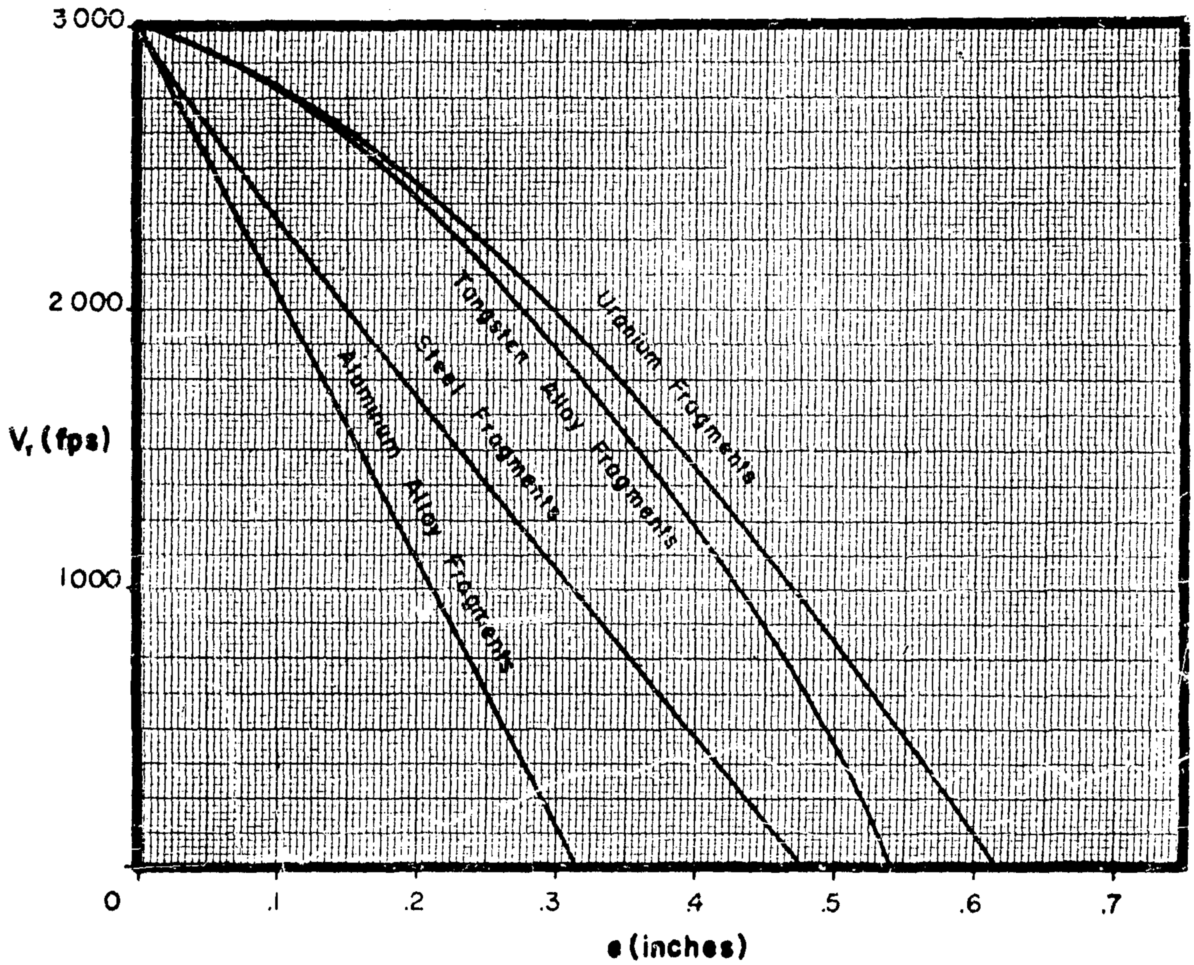
Comparison of the Performance of Fragments of Four Materials Impacting on Aluminum Alloy

A. Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Aluminum Alloy
Obliquity: 0°
Striking Velocity: 3000 fps

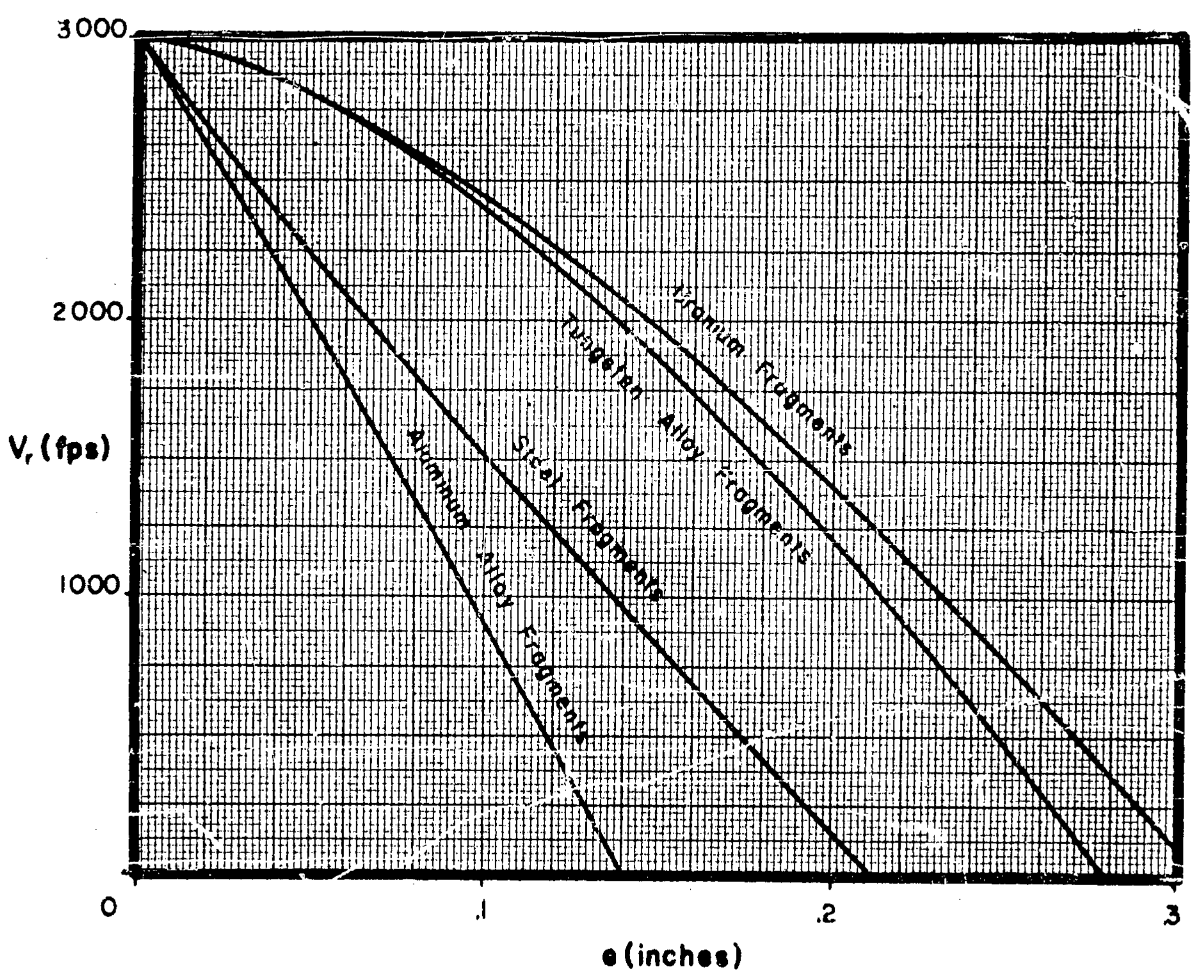
Fragment:
Type: BRL Pre-formed
Size: 30 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Aluminum Alloy
Obliquity: 60°
Striking Velocity: 3000 fps

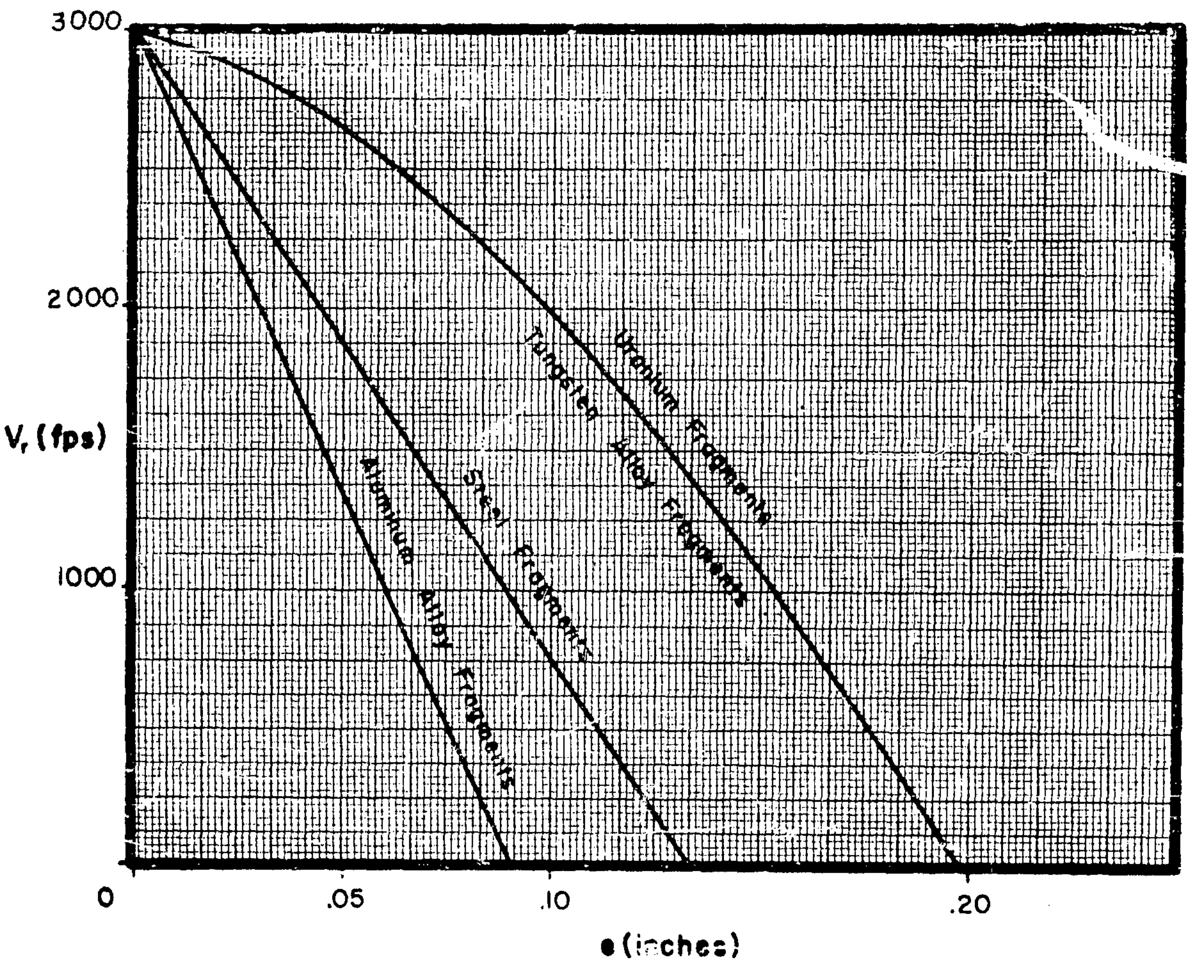
Fragment:
Type: BRL Pre-formed
Size: 30 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Aluminum Alloy
Obliquity: 70°
Striking Velocity: 3000 fps

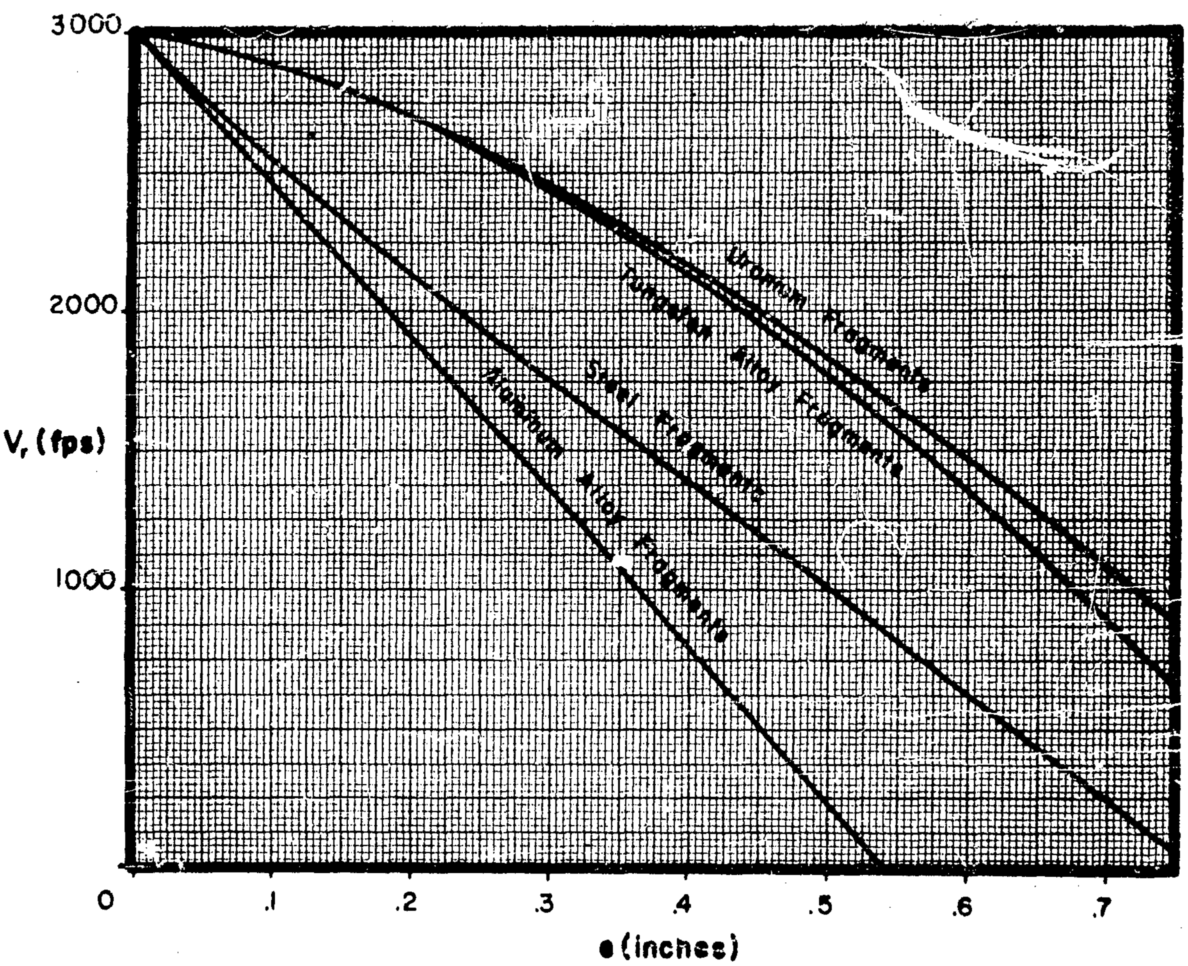
Fragment:
Type: BRL Pre-formed
Size: 30 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Aluminum Alloy
Obliquity: 0°
Striking Velocity: 3000 fps

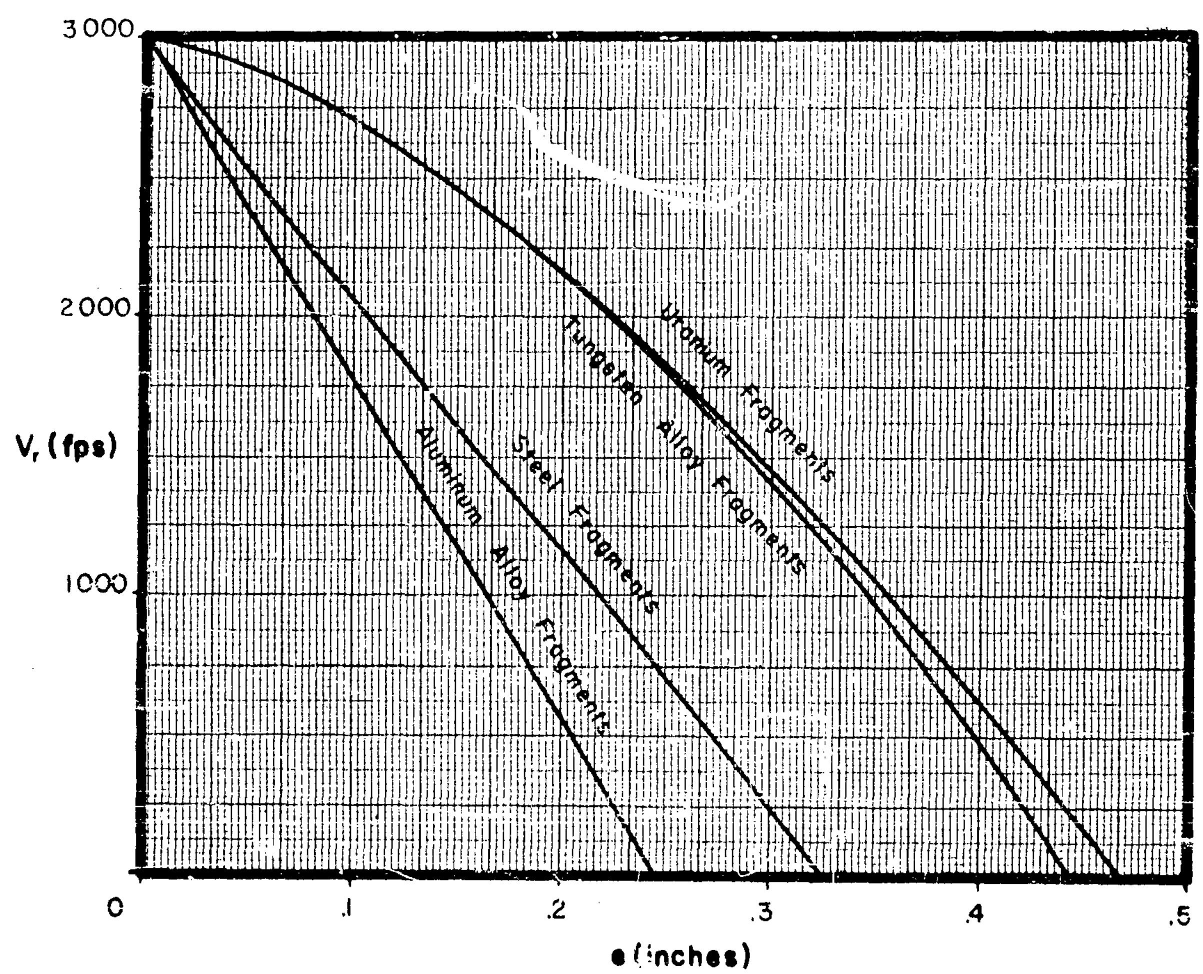
Fragment:
Type: BRL Pre-formed
Size: 100 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Aluminum Alloy
Obliquity: 60°
Striking Velocity: 3000 fps

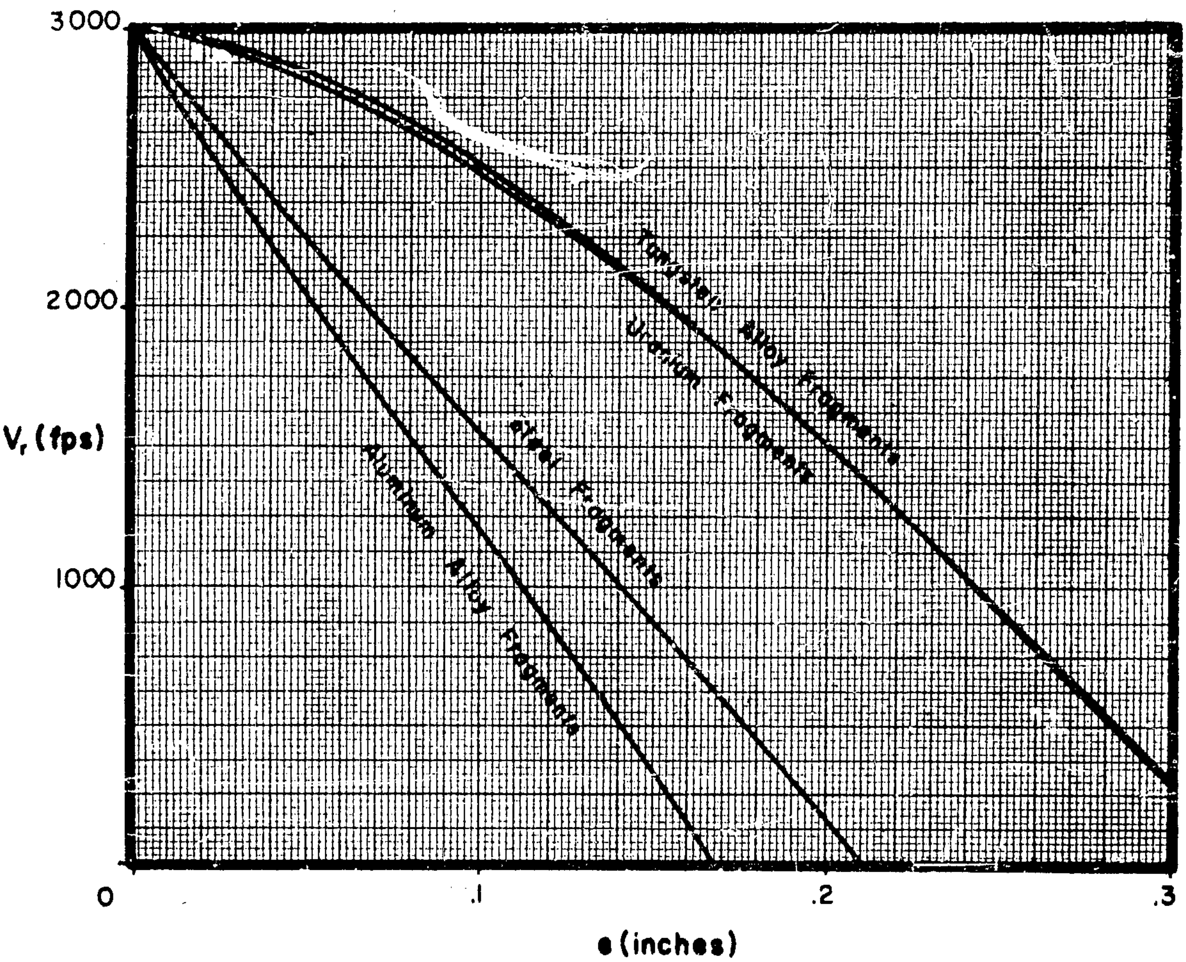
Fragment:
Type: BRL Pre-formed
Size: 100 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Aluminum Alloy
Obliquity: 70°
Striking Velocity: 3000 fps

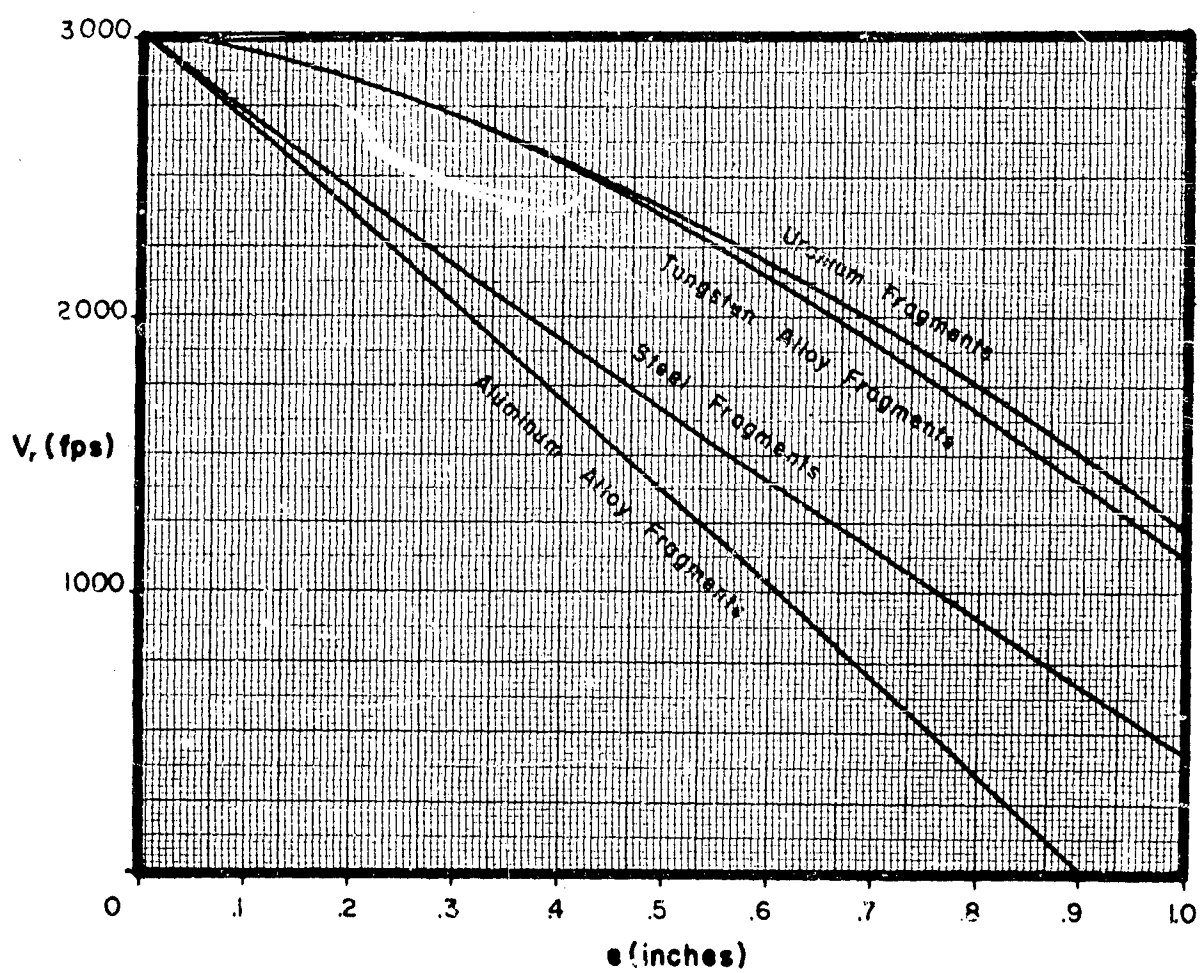
Fragment:
Type: BRL Pre-formed
Size: 100 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Aluminum Alloy
Obliquity: 0°
Striking Velocity: 3000 fps

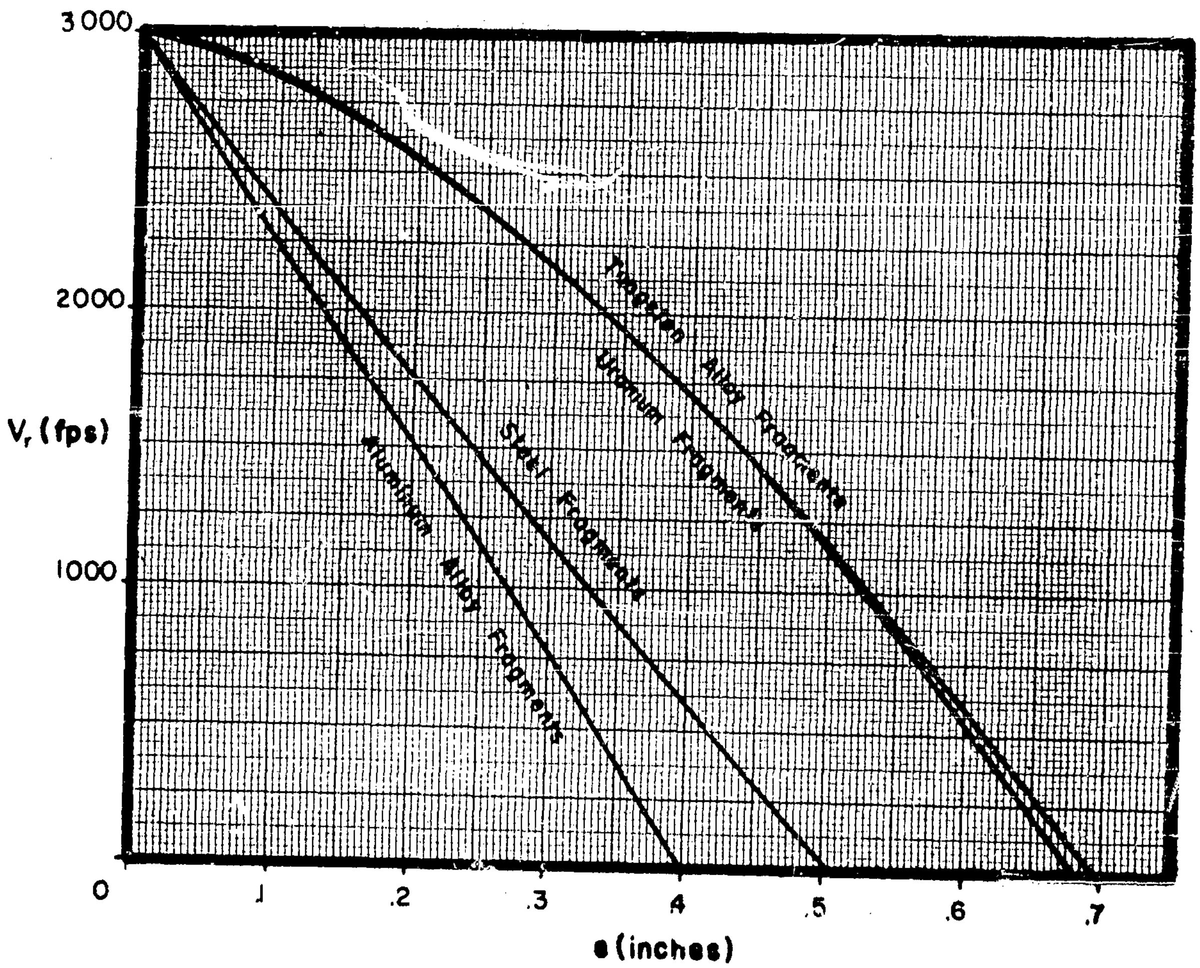
Fragment:
Type: BRL Pre-formed
Size: 300 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Aluminum Alloy
Obliquity: 60°
Striking Velocity: 3000 fps

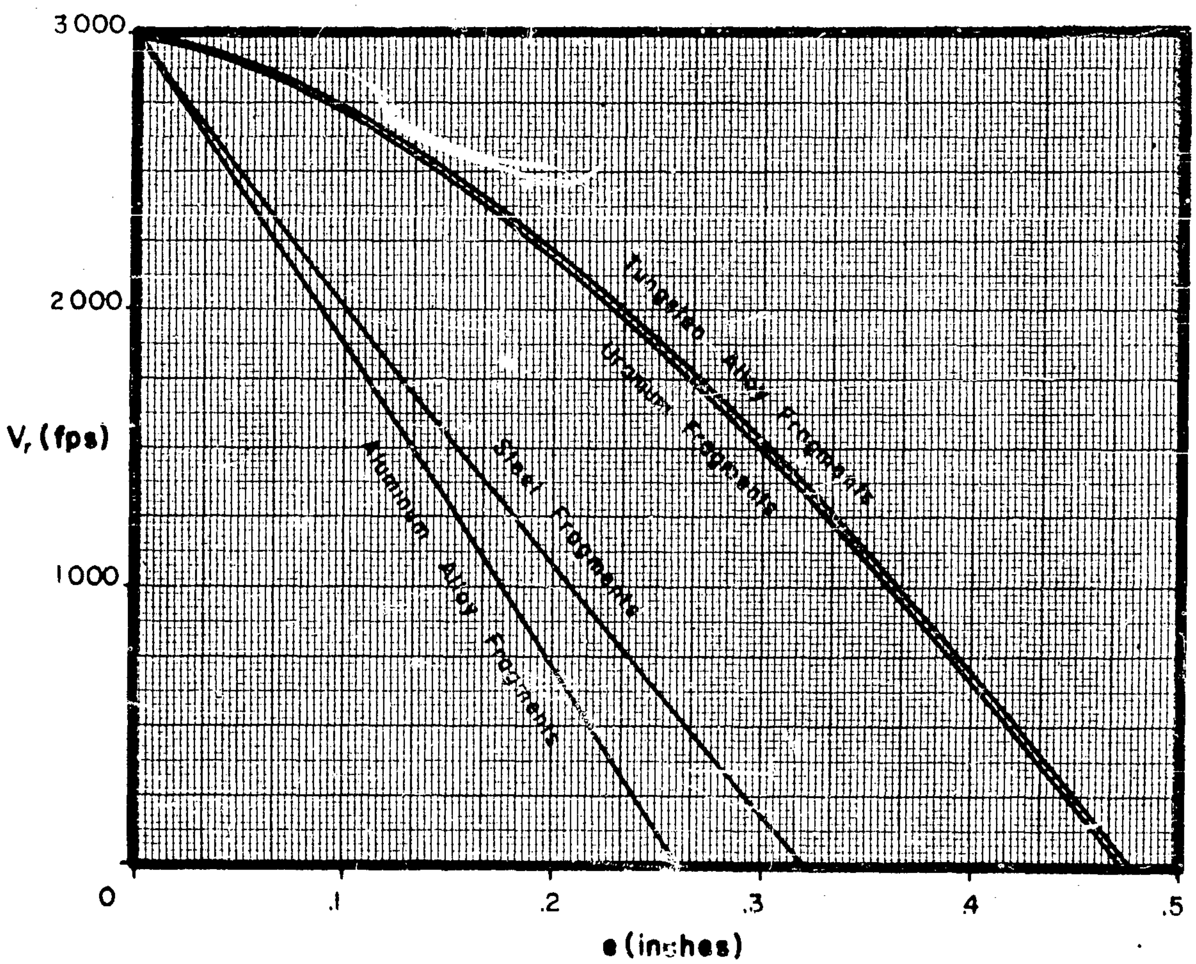
Fragment:
Type: BRL Pre-formed
Size: 300 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Aluminum Alloy
Obliquity: 70°
Striking Velocity: 3000 fps

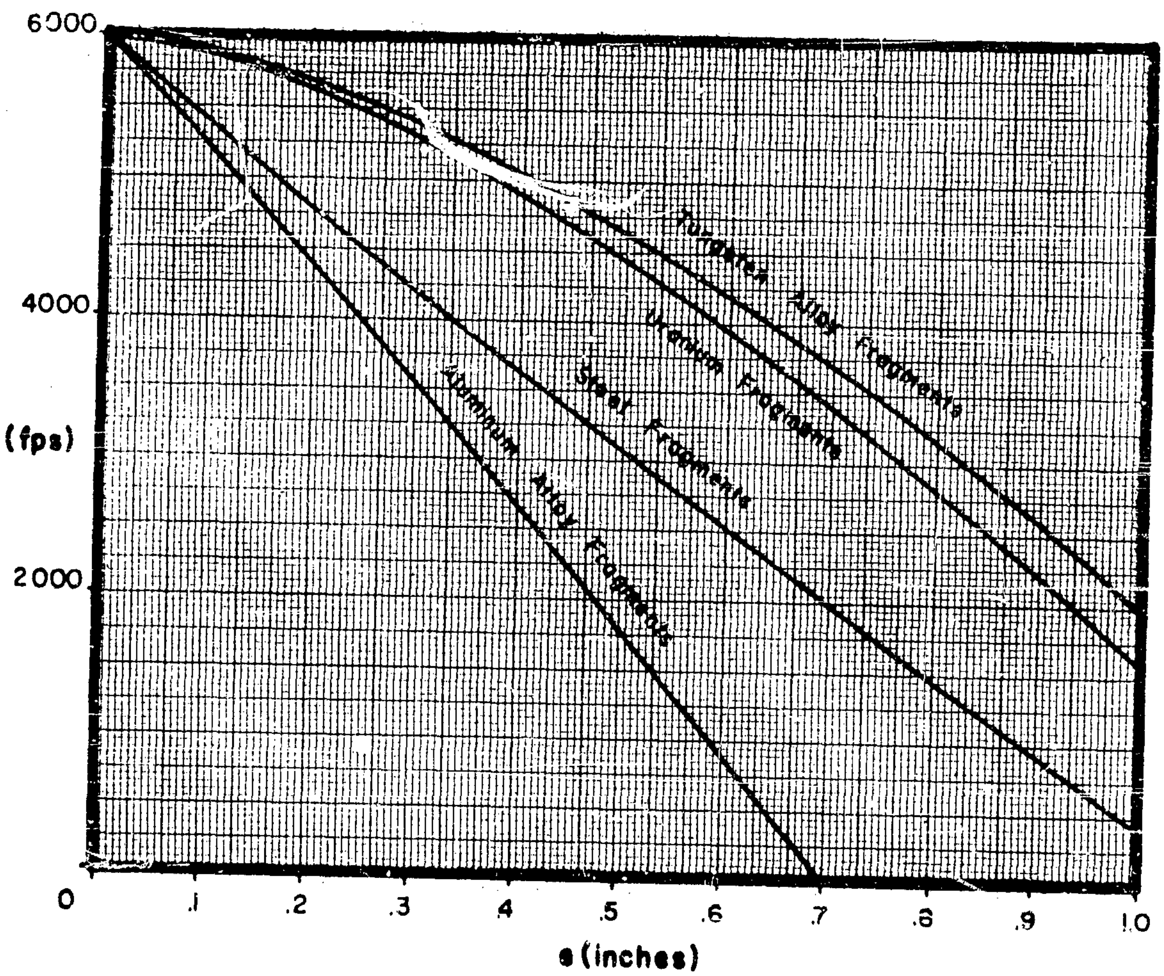
Fragment:
Type: BRL Pre-formed
Size: 300 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Aluminum Alloy
Obliquity: 0°
Striking Velocity: 6000 fps

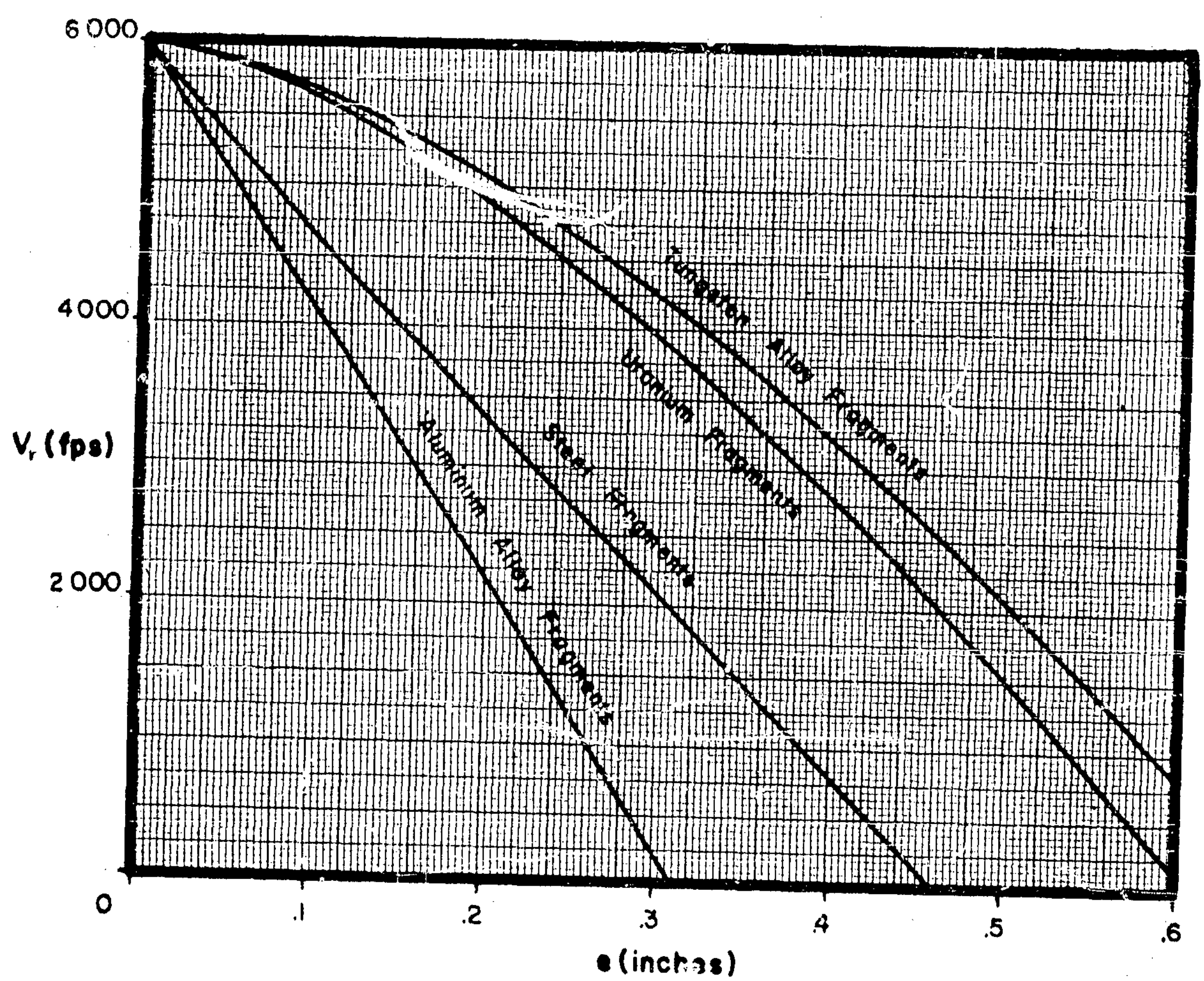
Fragment:
Type: BRL Pre-formed
Size: 30 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Aluminum Alloy
Obliquity: 60°
Striking Velocity: 6000 fps

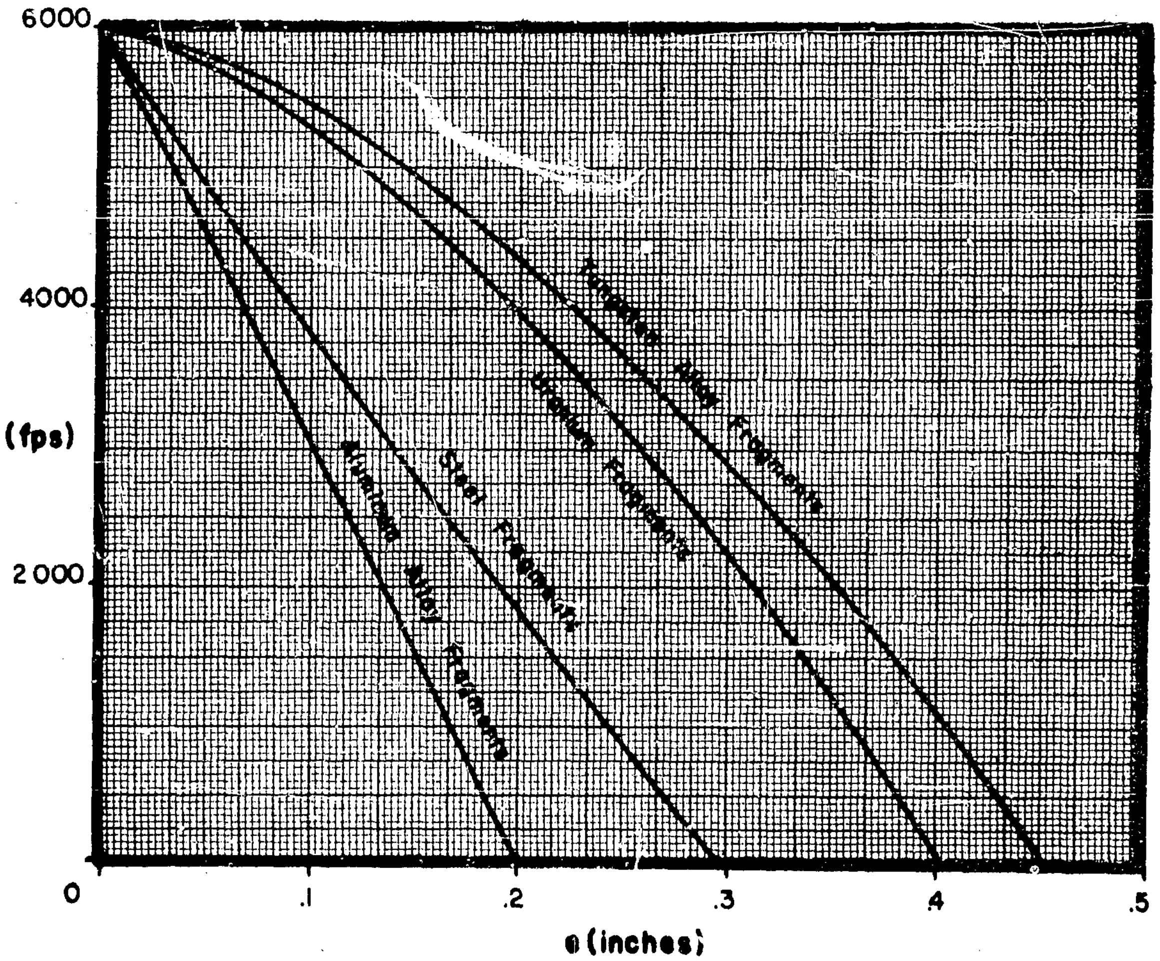
Fragment:
Type: BRL Pre-formed
Size: 30 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Aluminum Alloy
Obliquity: 70°
Striking Velocity: 6000 fps

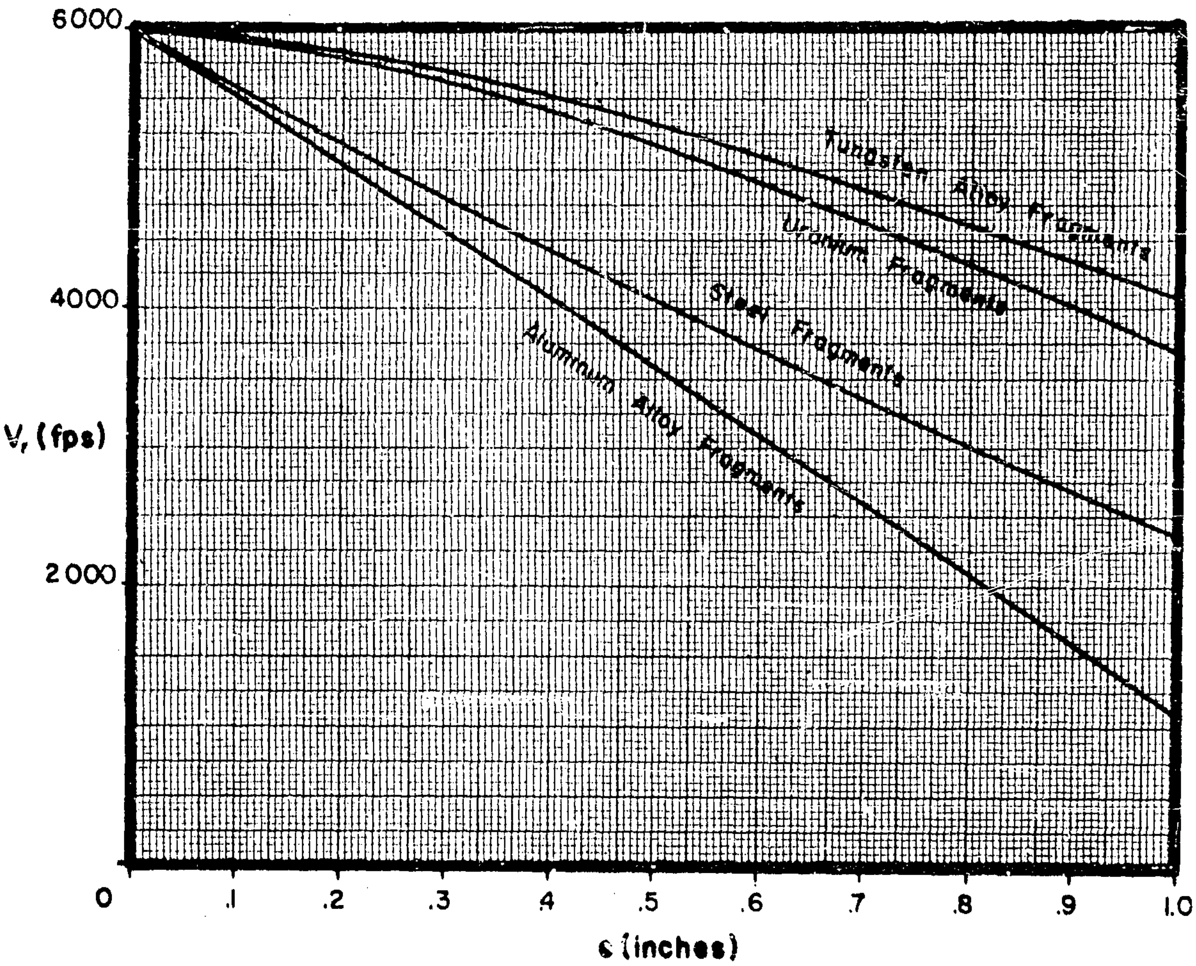
Fragment:
Type: BRL Pre-formed
Size: 30 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Aluminum Alloy
Obliquity: 0°
Striking Velocity: 6000 fps

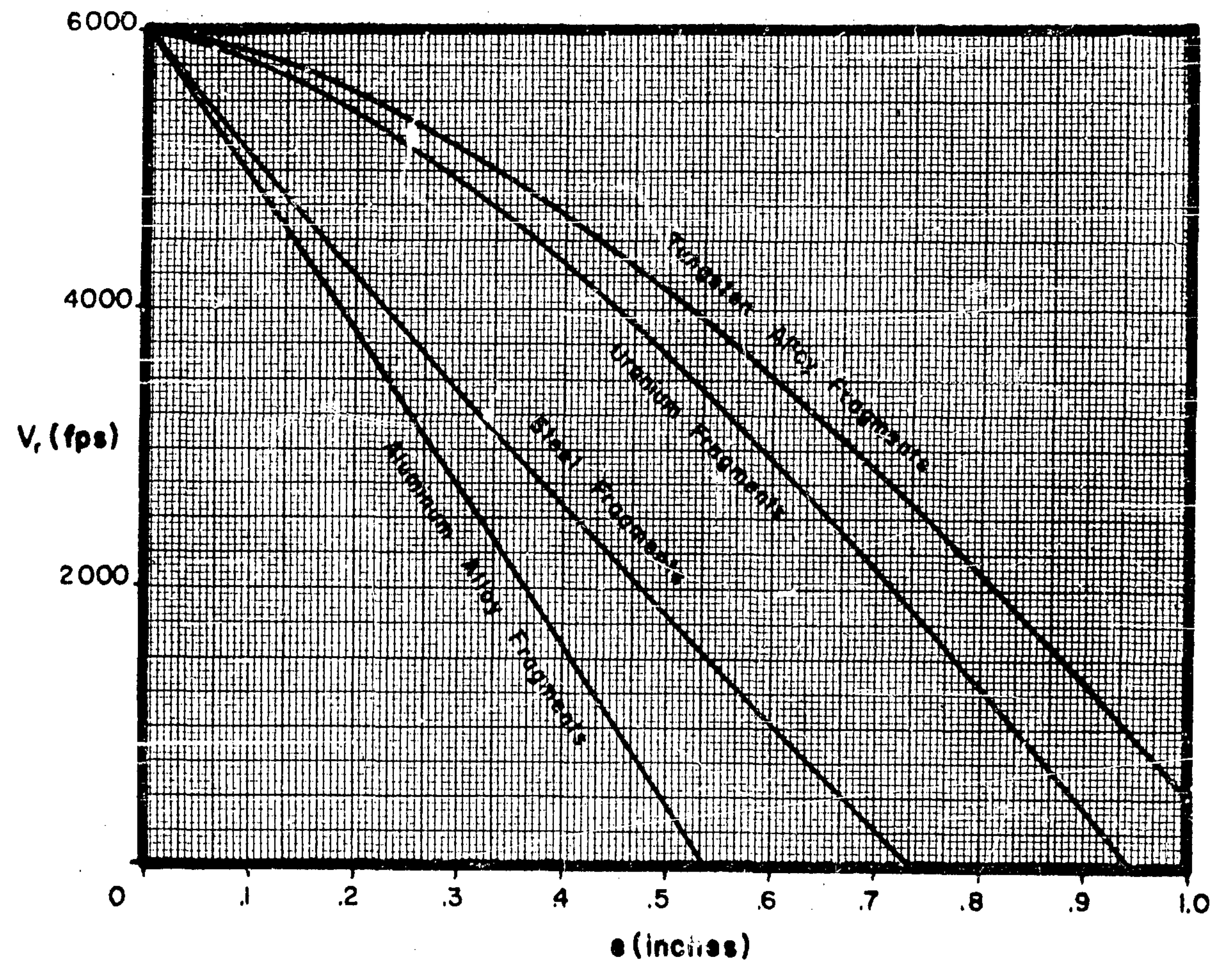
Fragment:
Type: BRL Pre-formed
Size: 100 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Aluminum Alloy
Obliquity: 60°
Striking Velocity: 6000 fps

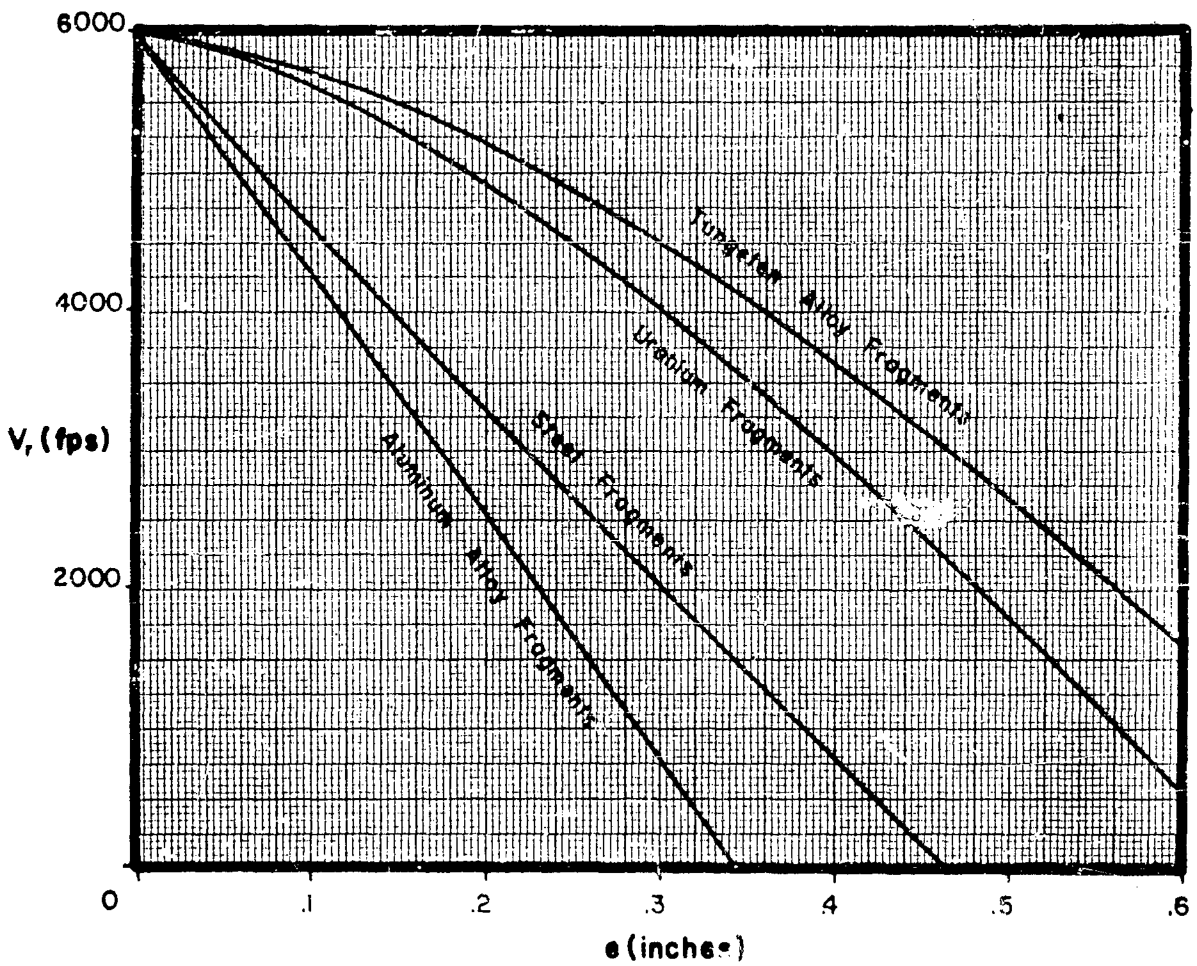
Fragment:
Type: BRL Pre-formed
Size: 100 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Aluminum Alloy
Obliquity: 70°
Striking Velocity: 6000 fps

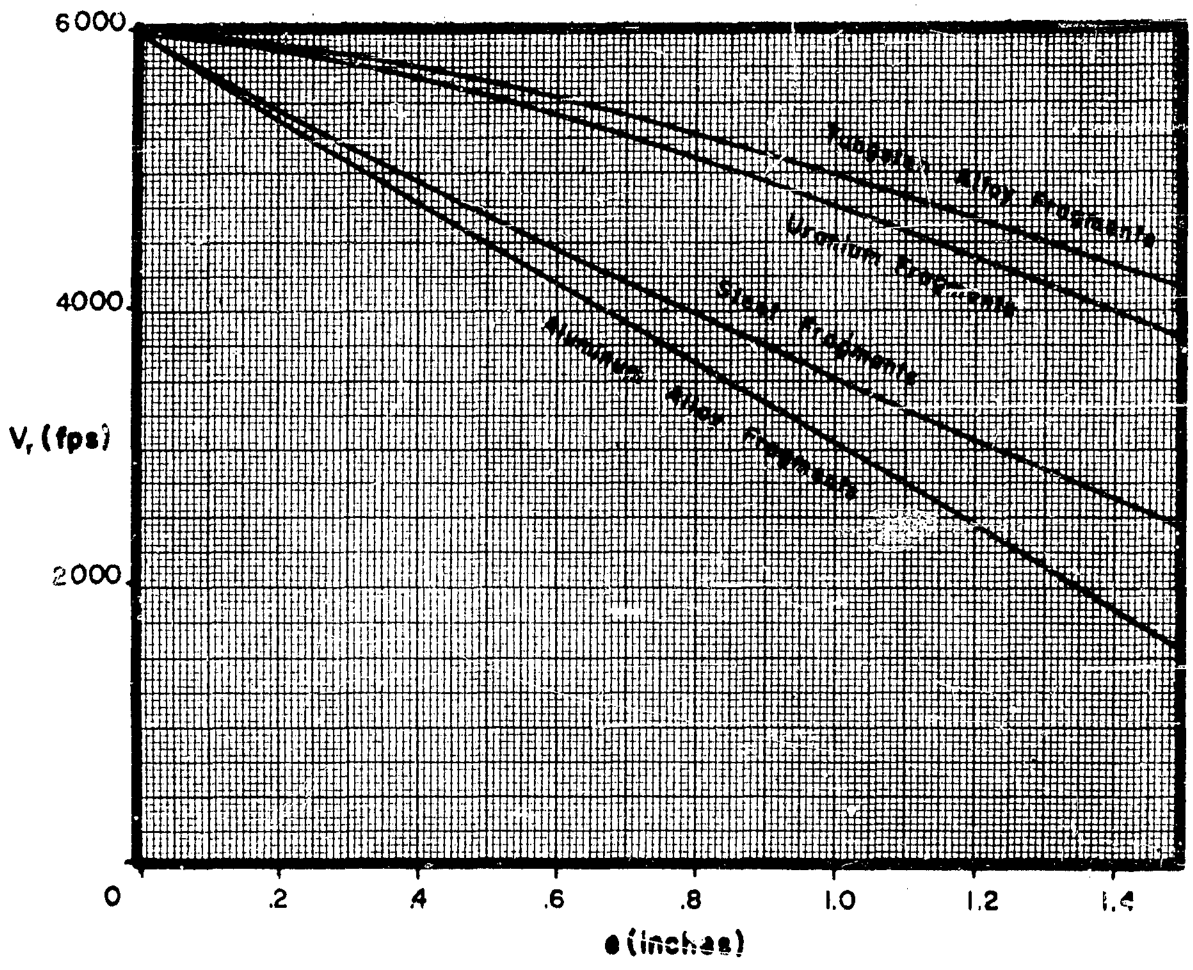
Fragment:
Type: BRL Pre-formed
Size: 100 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Aluminum Alloy
Obliquity: 0°
Striking Velocity: 6000 fps

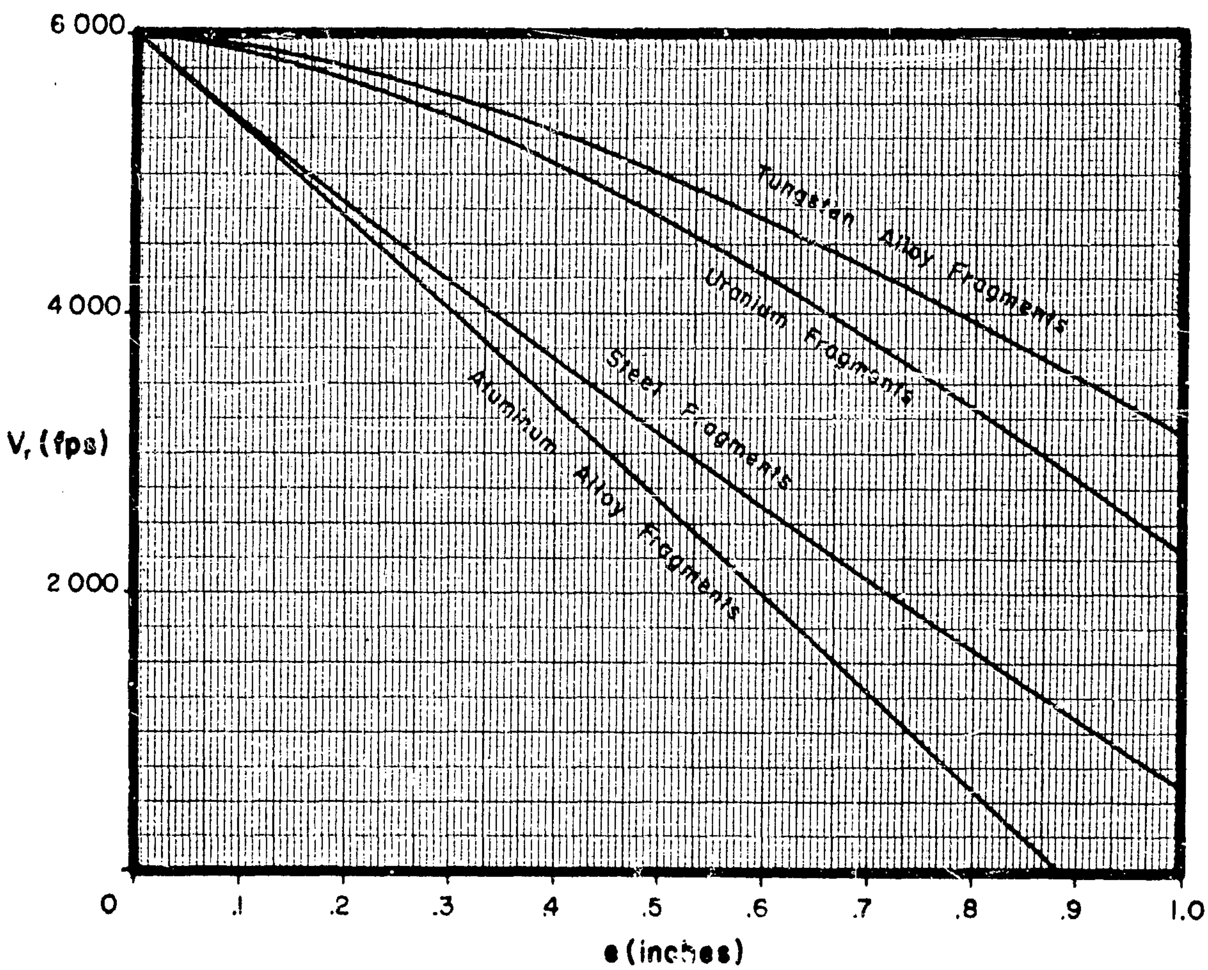
Fragment:
Type: BRL Pre-formed
Size: 300 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Aluminum Alloy
Obliquity: 60°
Striking Velocity: 6000 fps

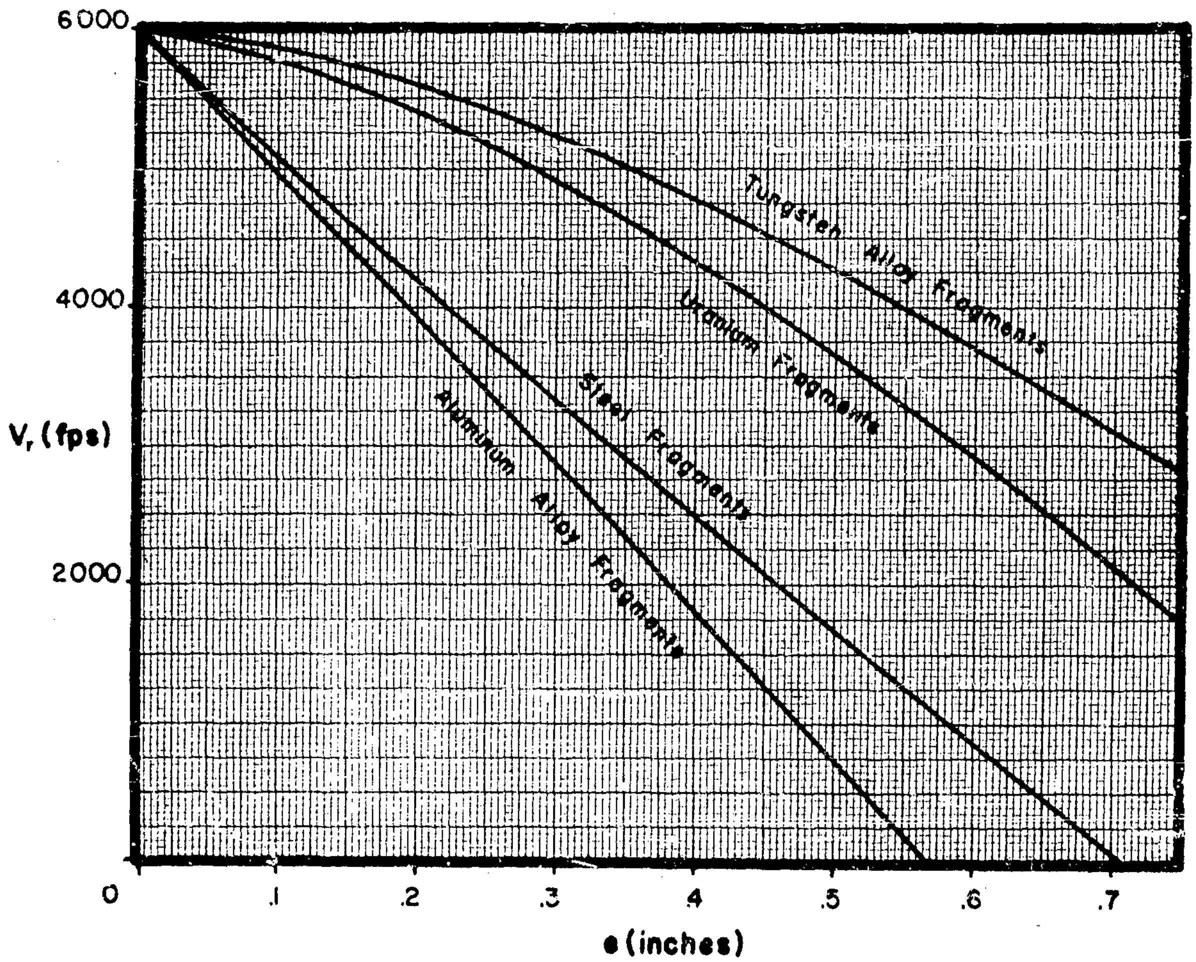
Fragment:
Type: BRL Pre-formed
Size: 300 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Aluminum Alloy
Obliquity: 70°
Striking Velocity: 6000 fps

Fragment:
Type: BRL Pre-formed
Size: 300 grains



APPENDIX IV

Comparison of the Performance of Fragments of Four Materials

Impacting on Aluminum Alloy

B. Plate Thickness vs Fragment Weight for Selected

Values of V_o and Angle of Obliquity

Plate Thickness vs Fragment Weight for Selected Combinations of V_o and Angle of Obliquity

Plate Material : Aluminum Alloy

V_o : 2000 fps

Obliquity : 0°

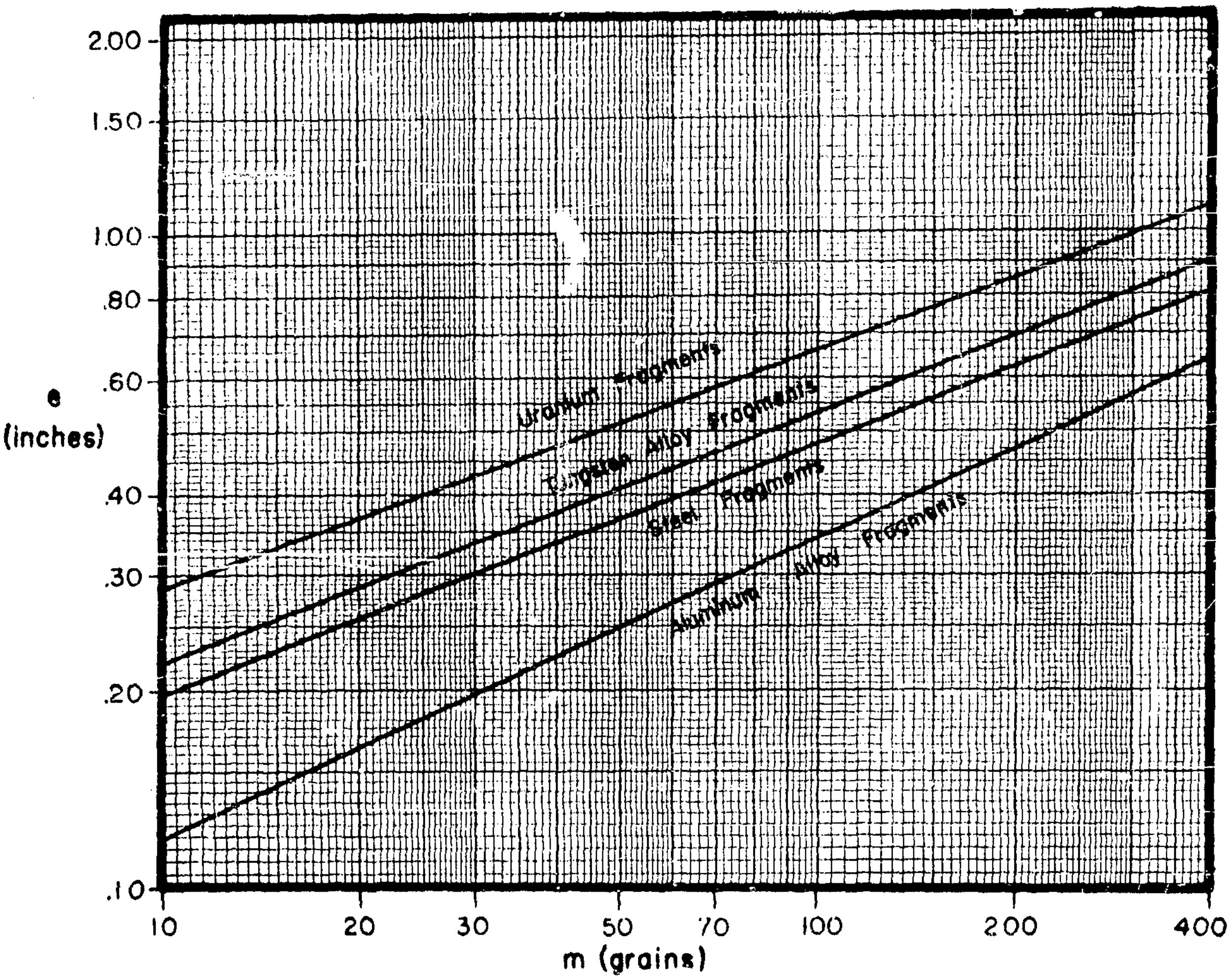


Plate Thickness vs Fragment Weight for Selected Combinations of V_o and Angle of Obliquity

Plate Material : Aluminum Alloy

V_o : 2000 fps

Obliquity : 60°

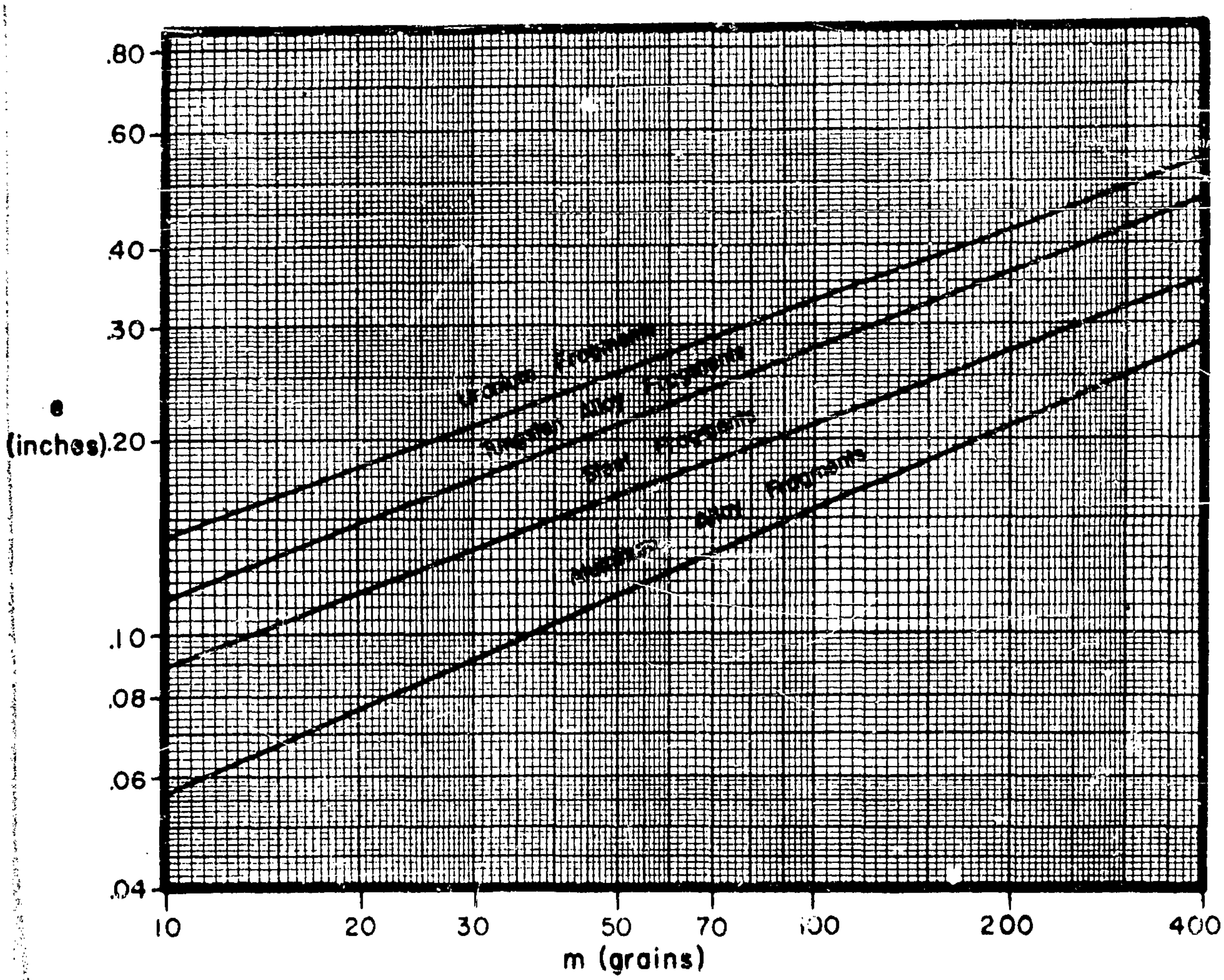


Plate Thickness vs Fragment Weight for Selected Combinations of V_o and Angle of Obliquity

Plate Material : Aluminum Alloy

V_o : 2000 f.ps

Obliquity : 70°

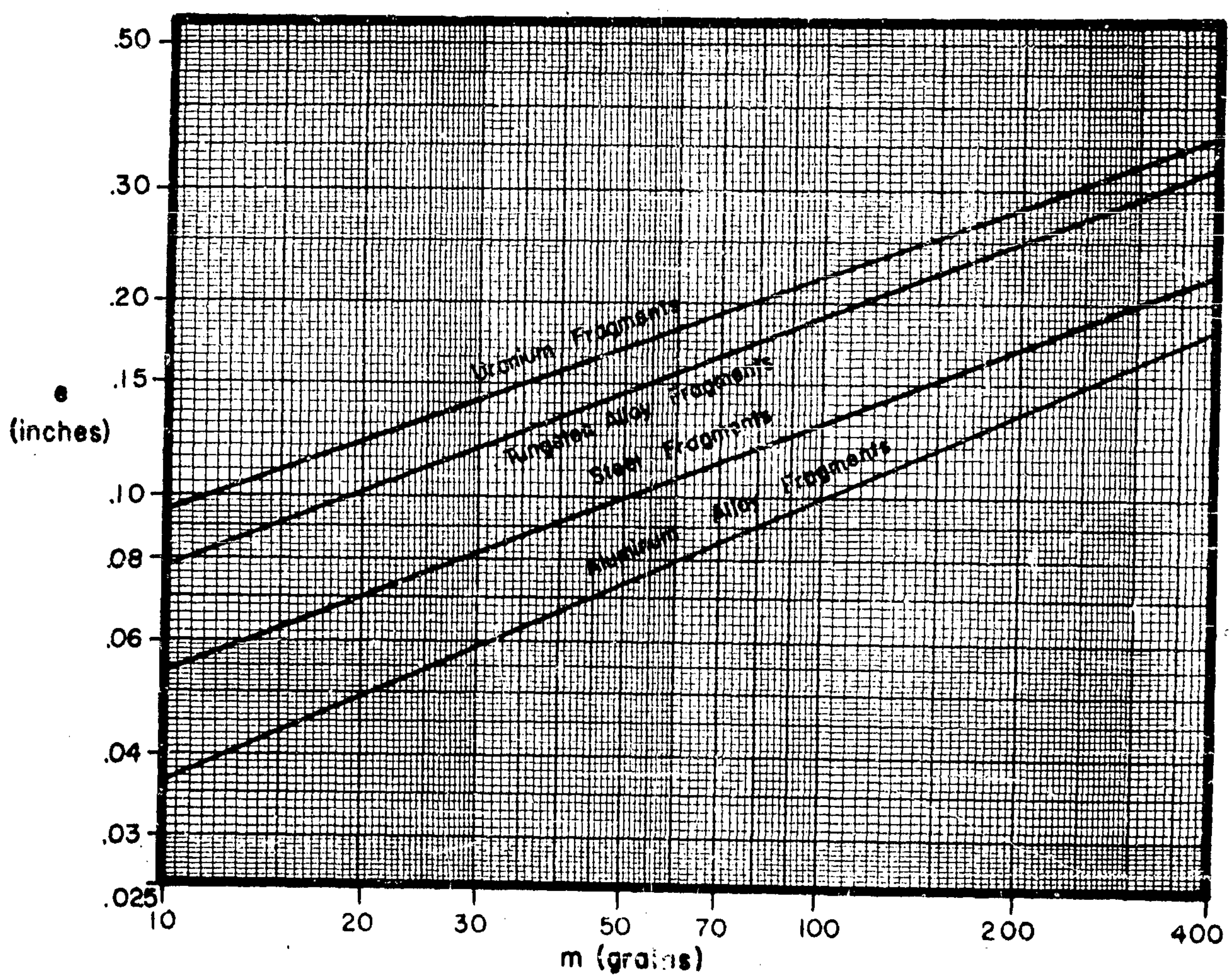


Plate Thickness vs Fragment Weight for Selected Combinations of V_o and Angle of Obliquity

Plate Material : Aluminum Alloy

V_o : 4000 fps

Obliquity : 0°

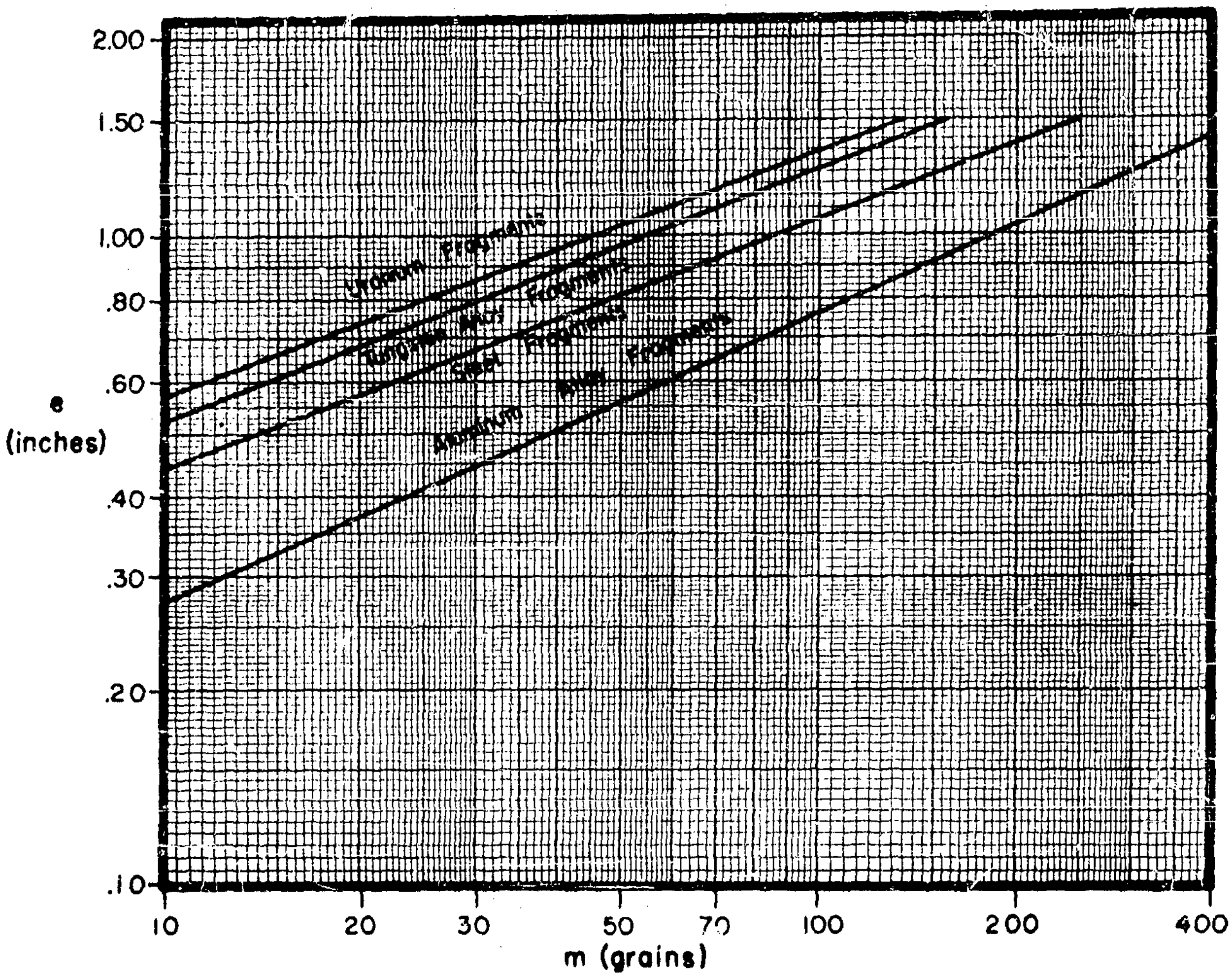


Plate Thickness vs Fragment Weight for Selected Combinations of V_o and Angle of Obliquity

Plate Material : Aluminum Alloy

V_o : 4000 fps

Obliquity : 60°

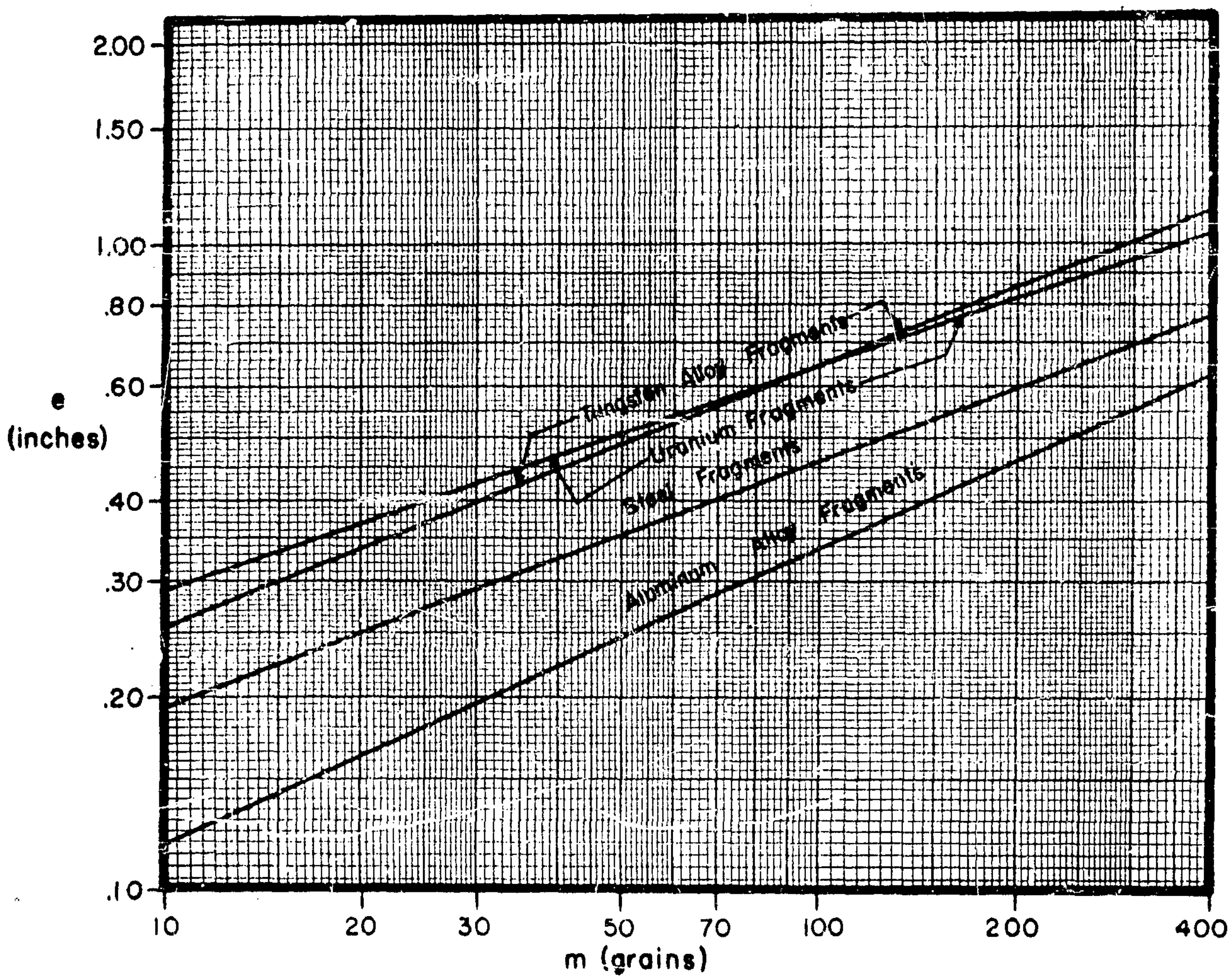


Plate Thickness vs Fragment Weight for Selected Combinations of V_o and Angle of Obliquity

Plate Material : Aluminum Alloy

V_o : 4000 f.ps

Obliquity : 70°

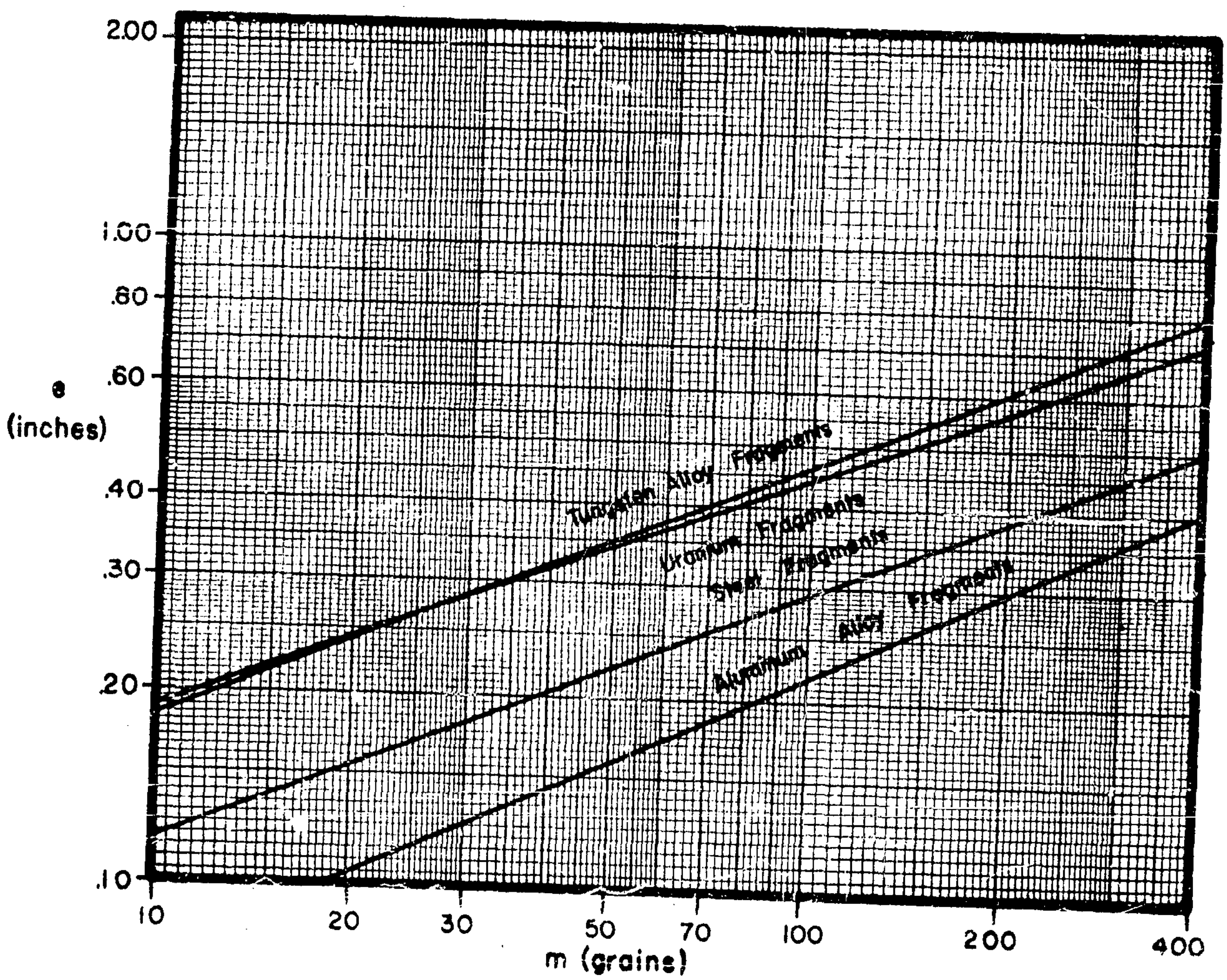


Plate Thickness vs Fragment Weight for Selected Combinations of V_o and Angle of Obliquity

Plate Material : Aluminum Alloy

V_o : 6000 fps

Obliquity : 0°

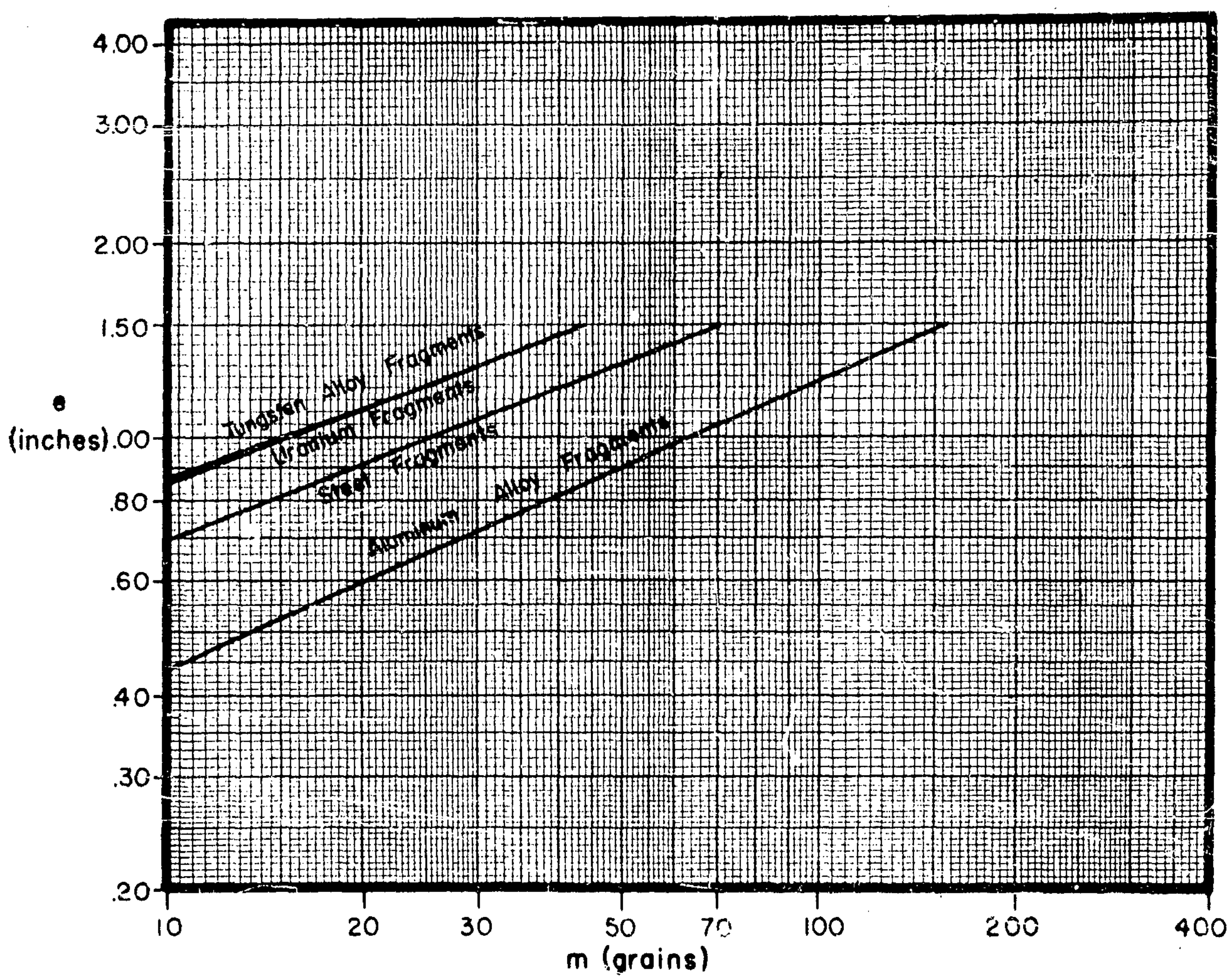


Plate Thickness vs Fragment Weight for Selected Combinations of V_o and Angle of Obliquity

Plate Material : Aluminum Alloy

V_o : 6000 fps

Obliquity : 60°

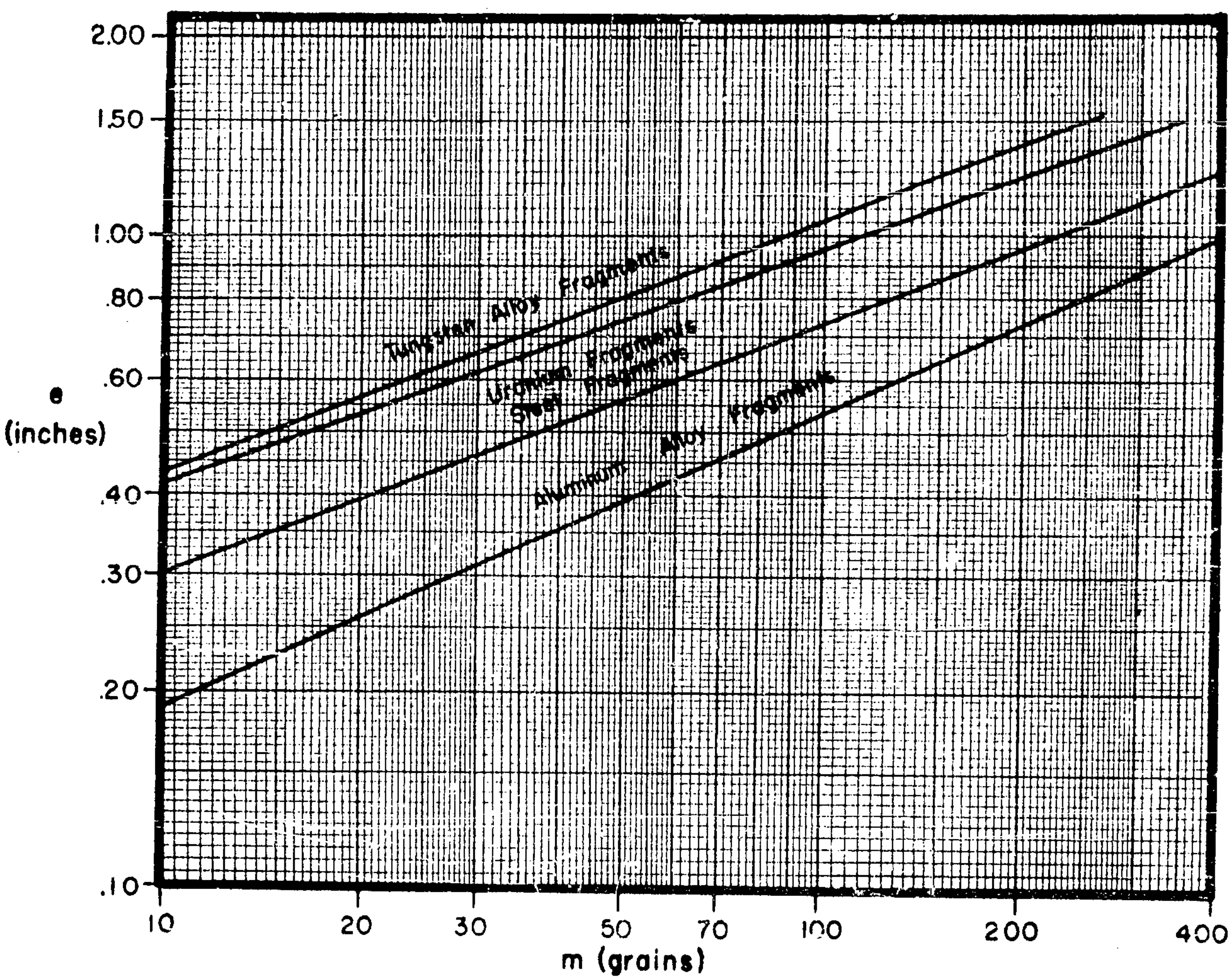
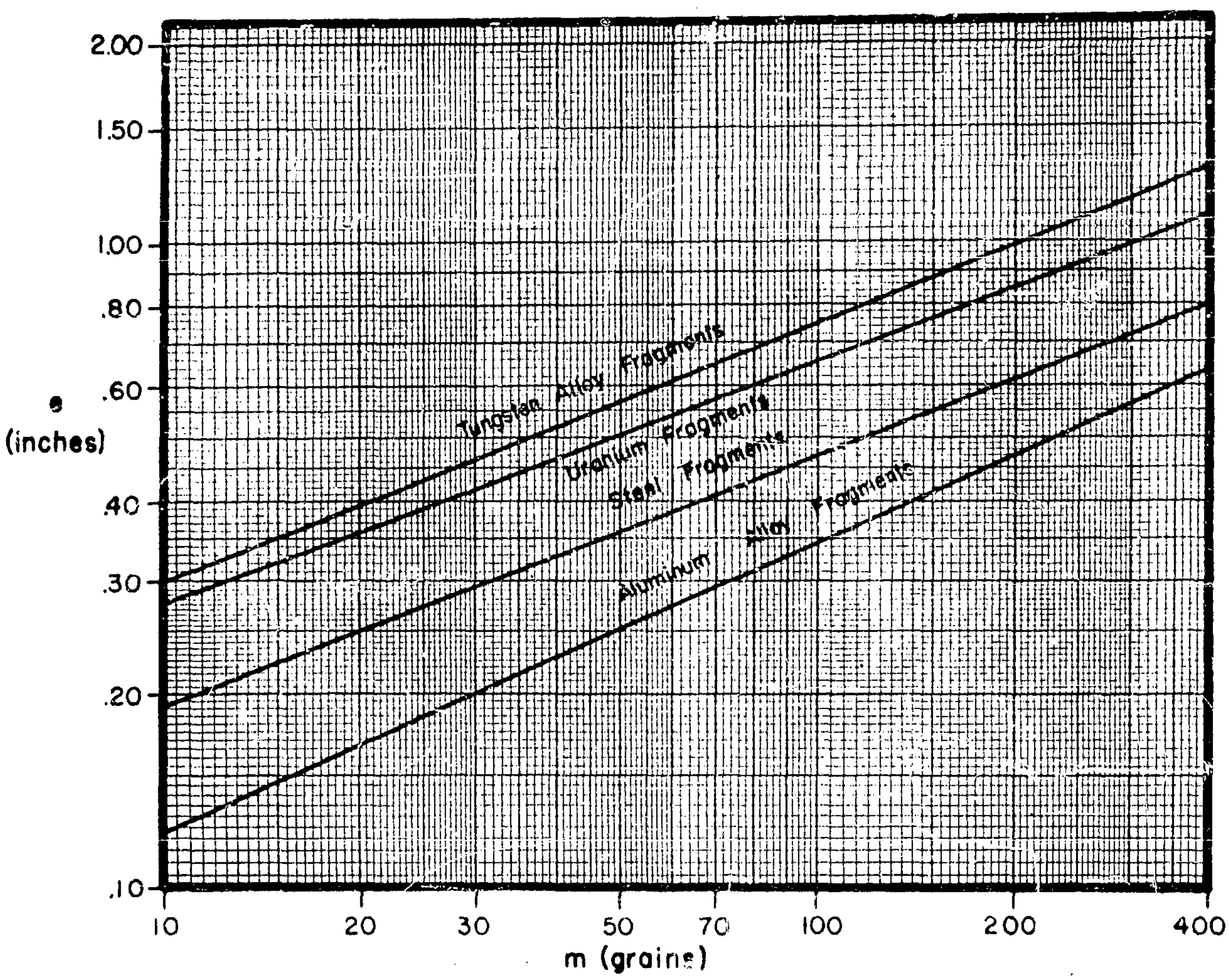


Plate Thickness vs Fragment Weight for Selected Combinations of V_o and Angle of Obliquity

Plate Material : Aluminum Alloy

V_o : 6000 f.ps

Obliquity : 70°



APPENDIX IV

Comparison of the Performance of Fragments of Four Materials Impacting on Aluminum Alloy

C. $(V_o)_X$ / $(V_o)_S$ vs Plate Thickness for Various Fragment Materials (X)

Comparison of Aluminum Alloy, Tungsten Alloy, and Uranium Fragments with Steel Fragments Impacting on Aluminum Alloy Plate

$\bar{r}$ vs e for Three Obliquities

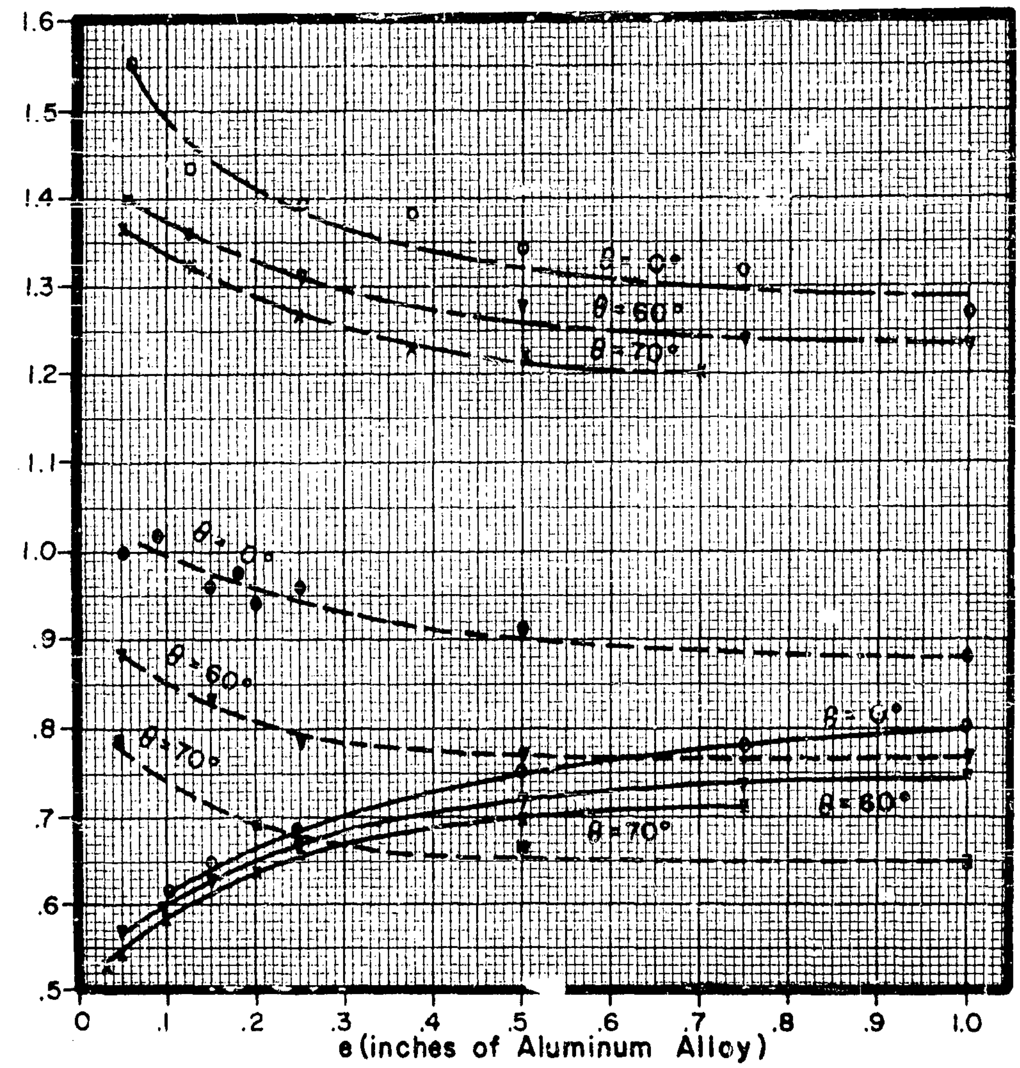
Fragment Materials (X)

— - — Aluminum Alloy
- - - - Tungsten Alloy
—— Uranium

NOTE: 1. $r = \frac{(V_o)_x}{(V_o)_s}$

2. $\bar{r}$ is the Average of the Values of r Corresponding to Selected Values of Fragment Weights for Any Given Set of Values of Obliquity and Material Thickness

3. Parameter Combinations Selected to Meet the Requirement that $(V_o)_s \geq 400$ fps



APPENDIX IV

Comparison of the Performance of Fragments of Four Materials

Impacting on Aluminum Alloy

D. $(V_r)_X$ / $(V_r)_S$ vs Plate Thickness for Various

Fragment Materials (X)

Comparison of Aluminum Alloy, Tungsten Alloy, and Uranium Fragments with Steel Fragments Impacting on Aluminum Alloy Plate

$\overline{R}$ vs e for Three Obliquities

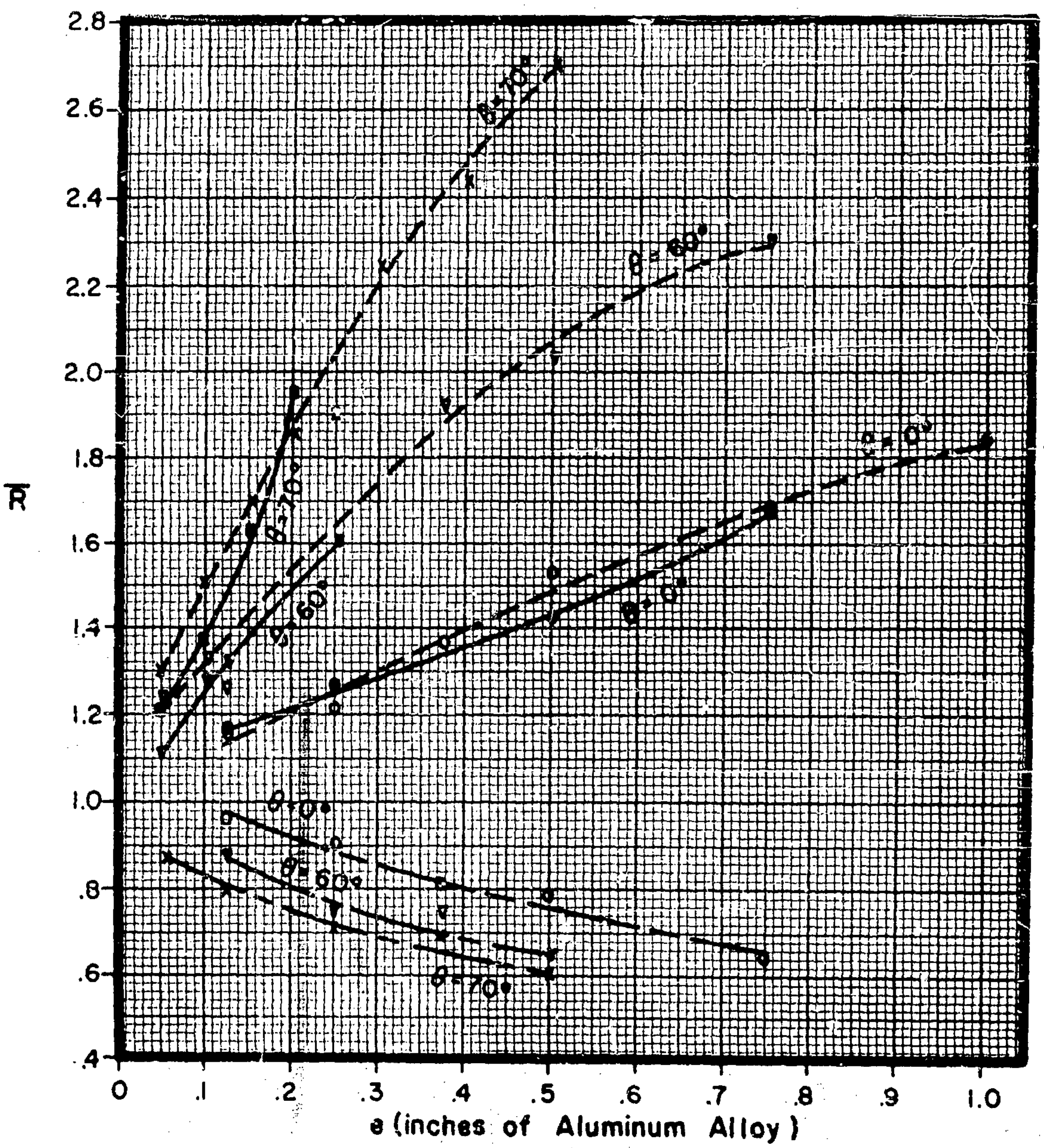
NOTE: 1. $R = \frac{(V_r)_x}{(V_r)_s}$

2. $\overline{R}$ is the Average of the Values of R for Various Fragment Weights and Striking Velocities; thus $\overline{R}$ Depends Only on e and θ

3. Parameter Combinations Selected to Meet the Requirement that $(V_r)_s \geq 1000$ fps

Fragment Materials (X)

- ——— Aluminum Alloy
- - - - Tungsten Alloy
- ——— Uranium



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APPENDIX V

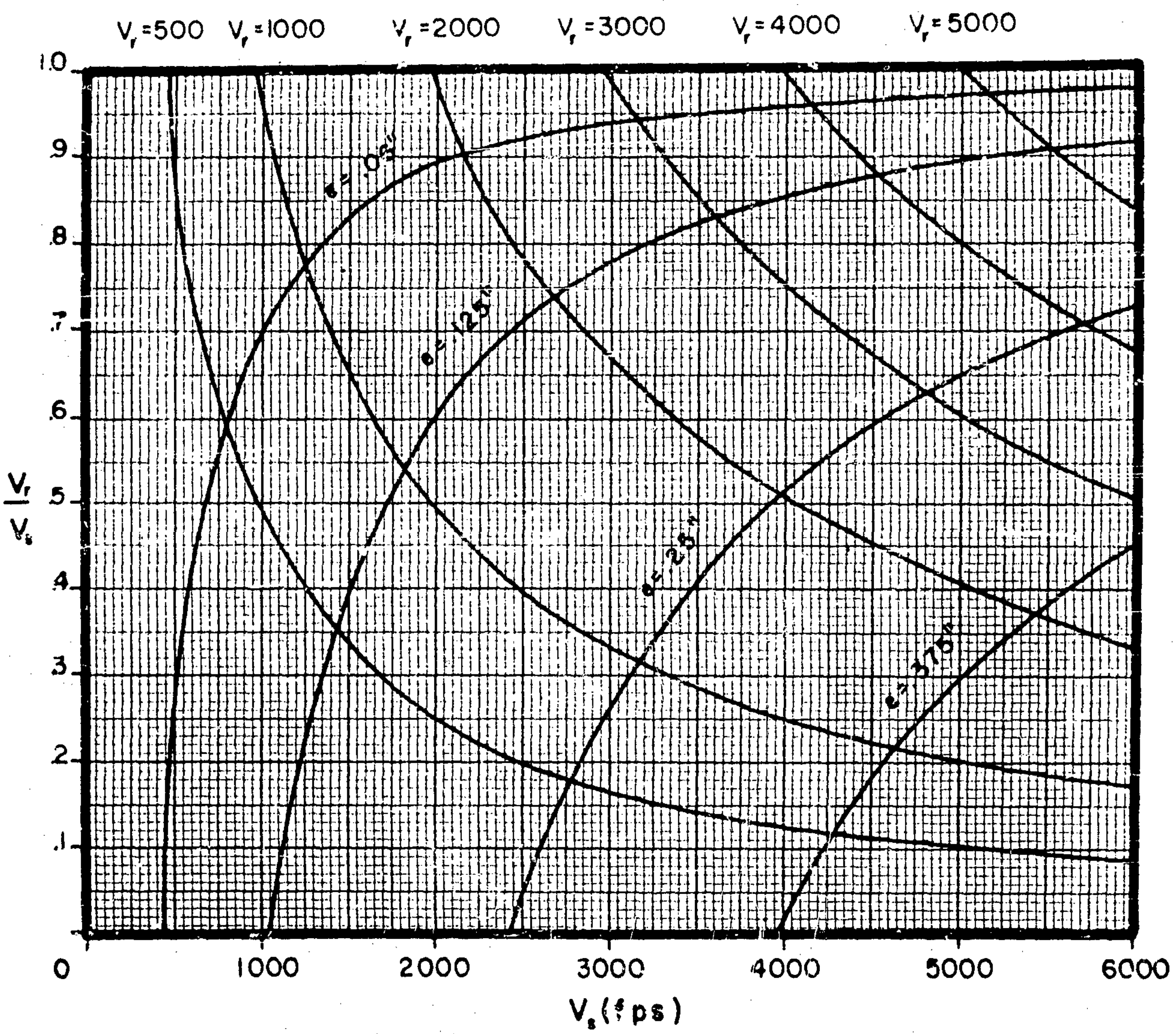
Tungsten Alloy Fragments vs Steel Plate (B ~ 100)

A. Residual Velocity/Striking Velocity vs Striking Velocity for Selected Plate Thicknesses

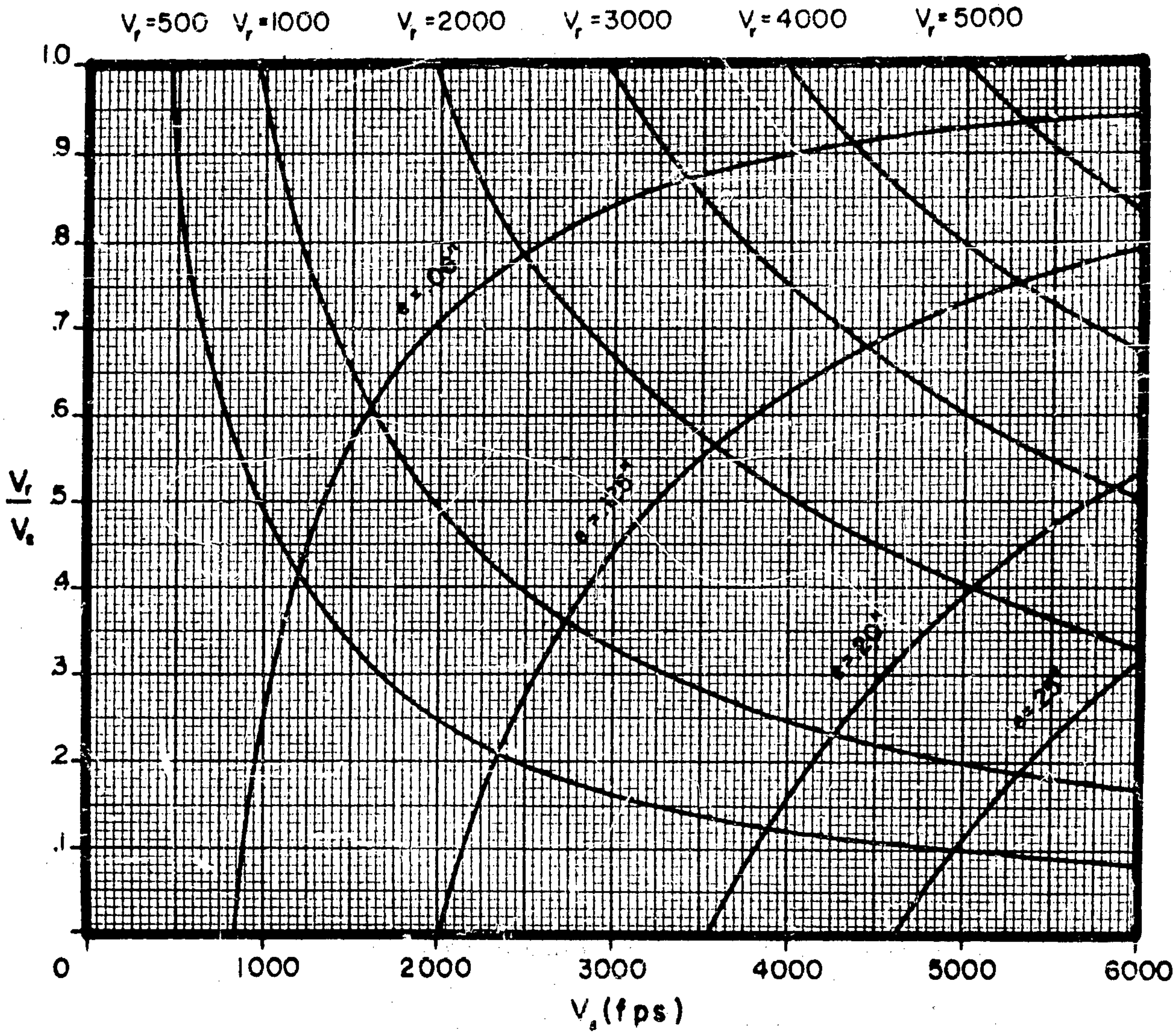
Residuai Ve
Striking Ve
for Sele

Plate Material: Steel ('
Obliquity: 0°

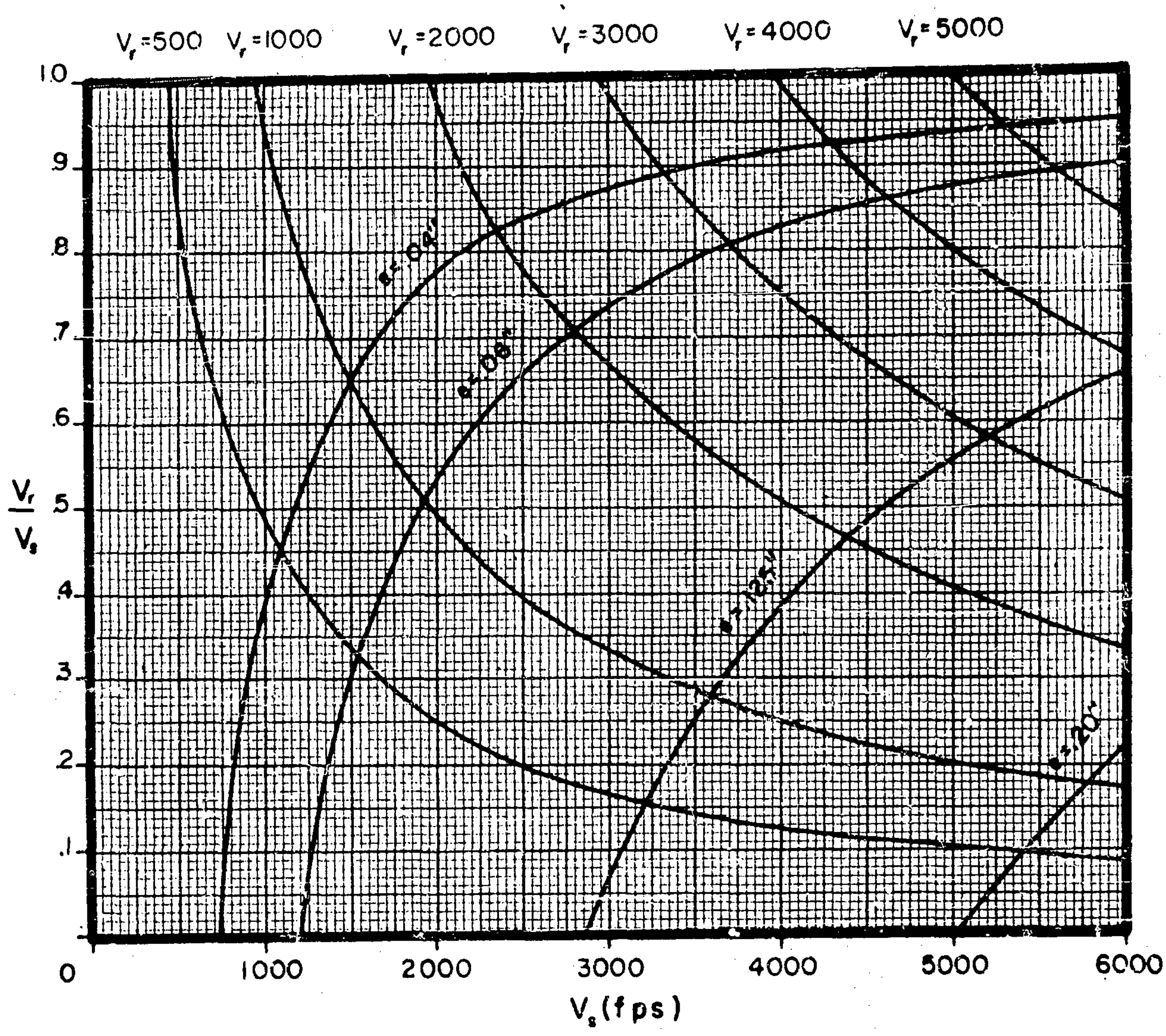
Materiai: Tungsten
Size: 30 grains



Size: 30 grains



-formed
n Alloy



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Residual Velocity / Striking Velocity vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B~100)

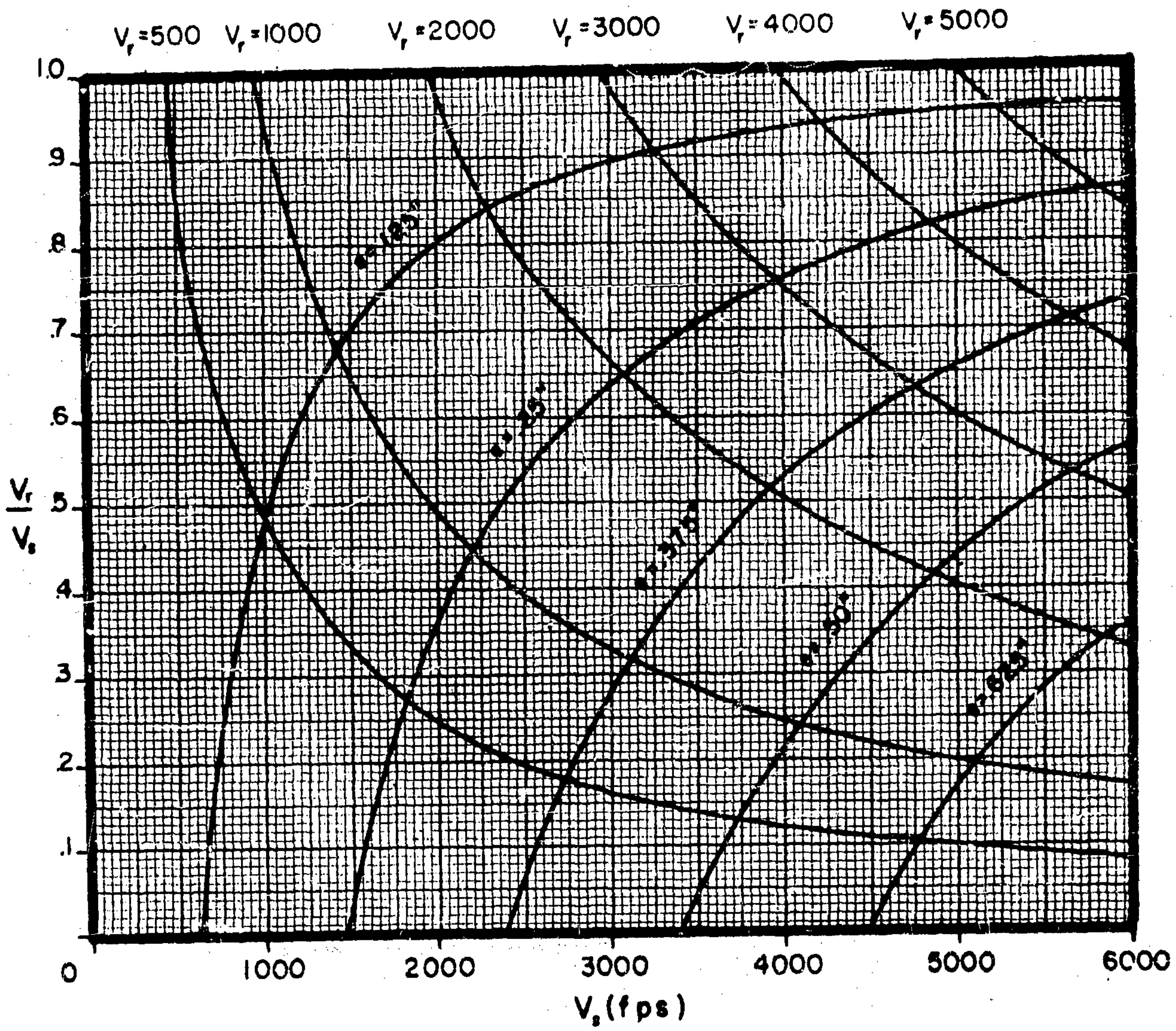
Obliquity: 0°

Fragment:

Type: BRL Pre-formed

Material: Tungsten Alloy

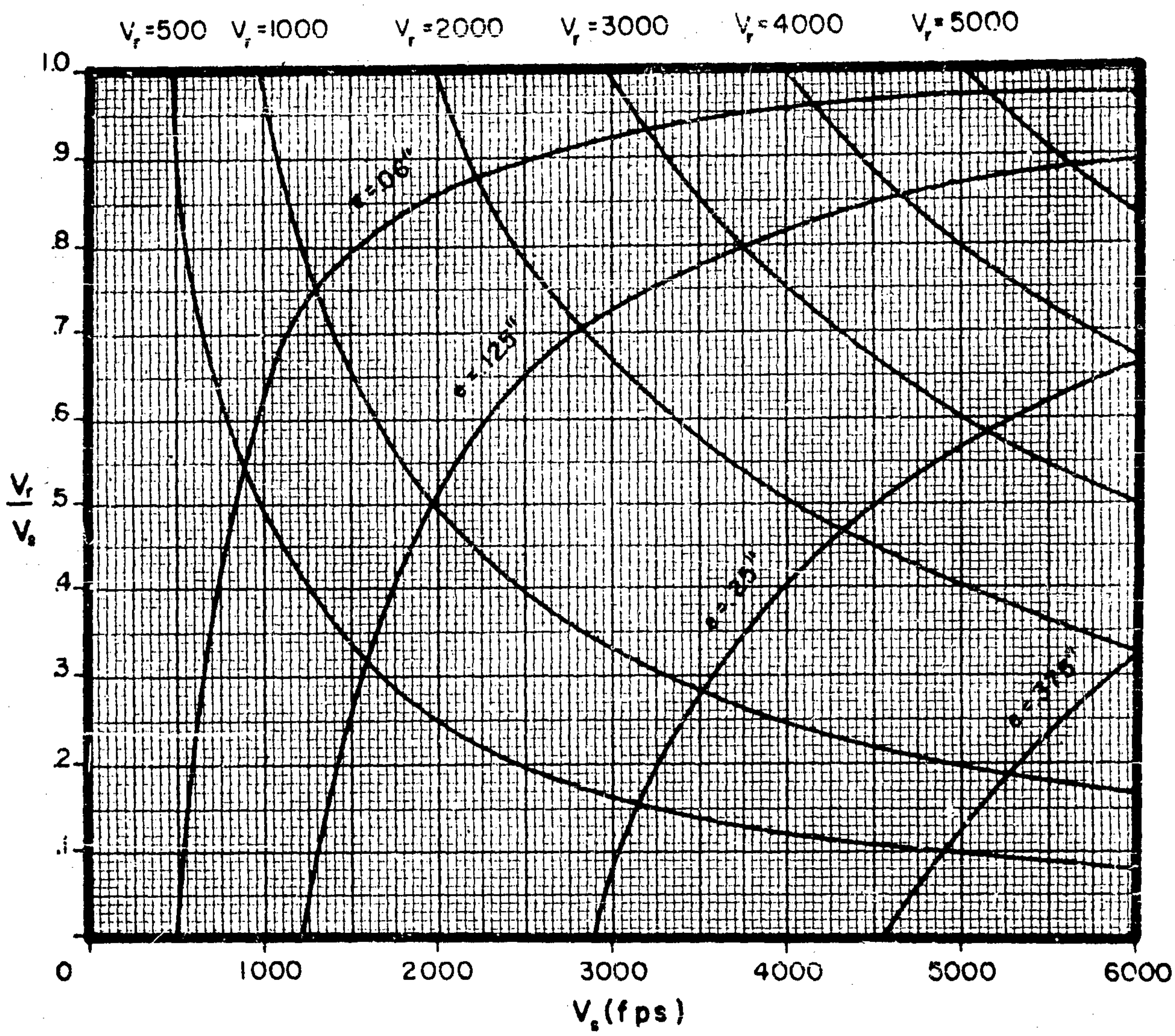
Size: 100 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B~100)
Obliquity: 60°

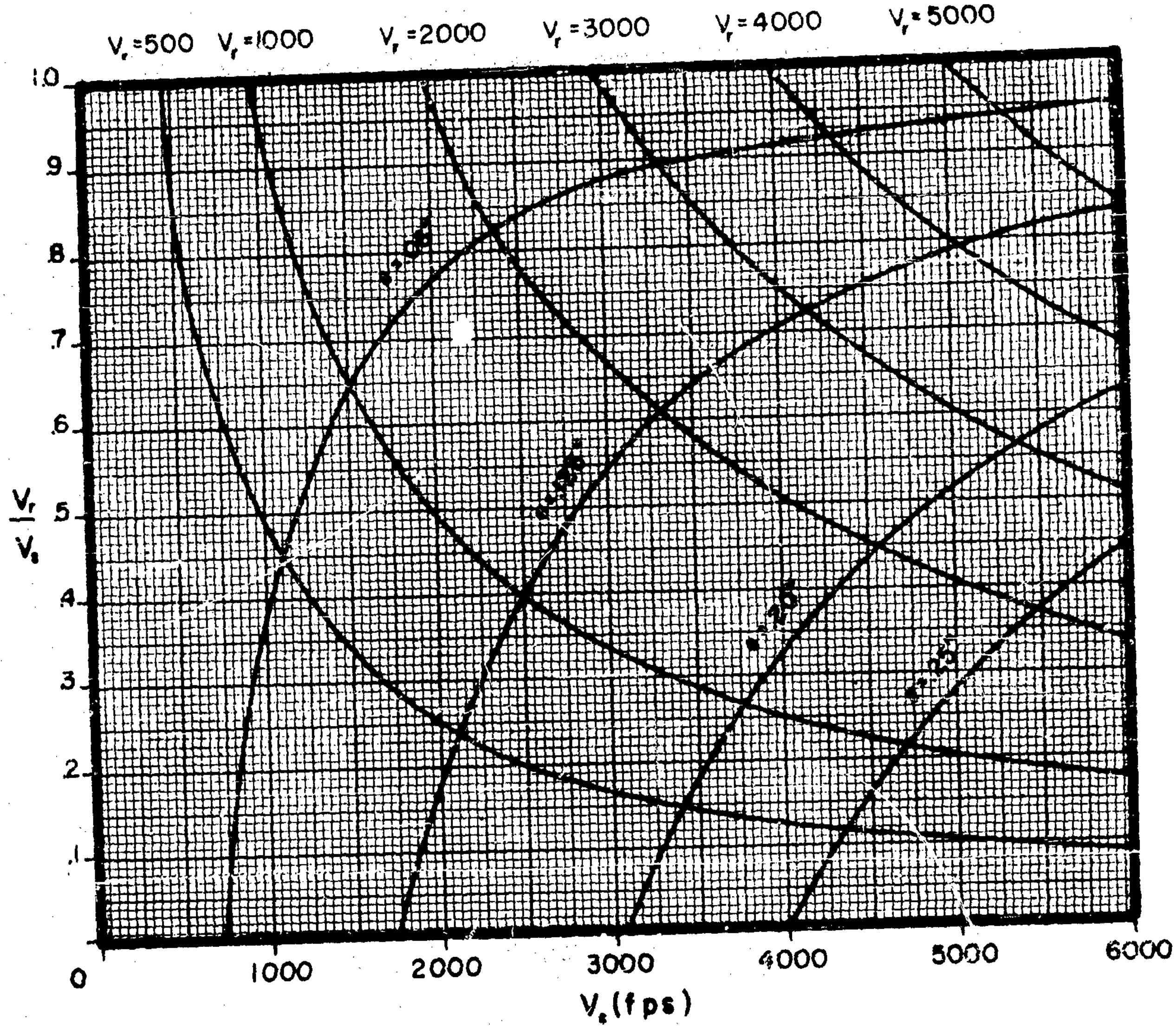
Fragment:
Type: BRL Pre-formed
Material: Tungsten Alloy
Size: 100 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B~100)
Obliquity: 70°

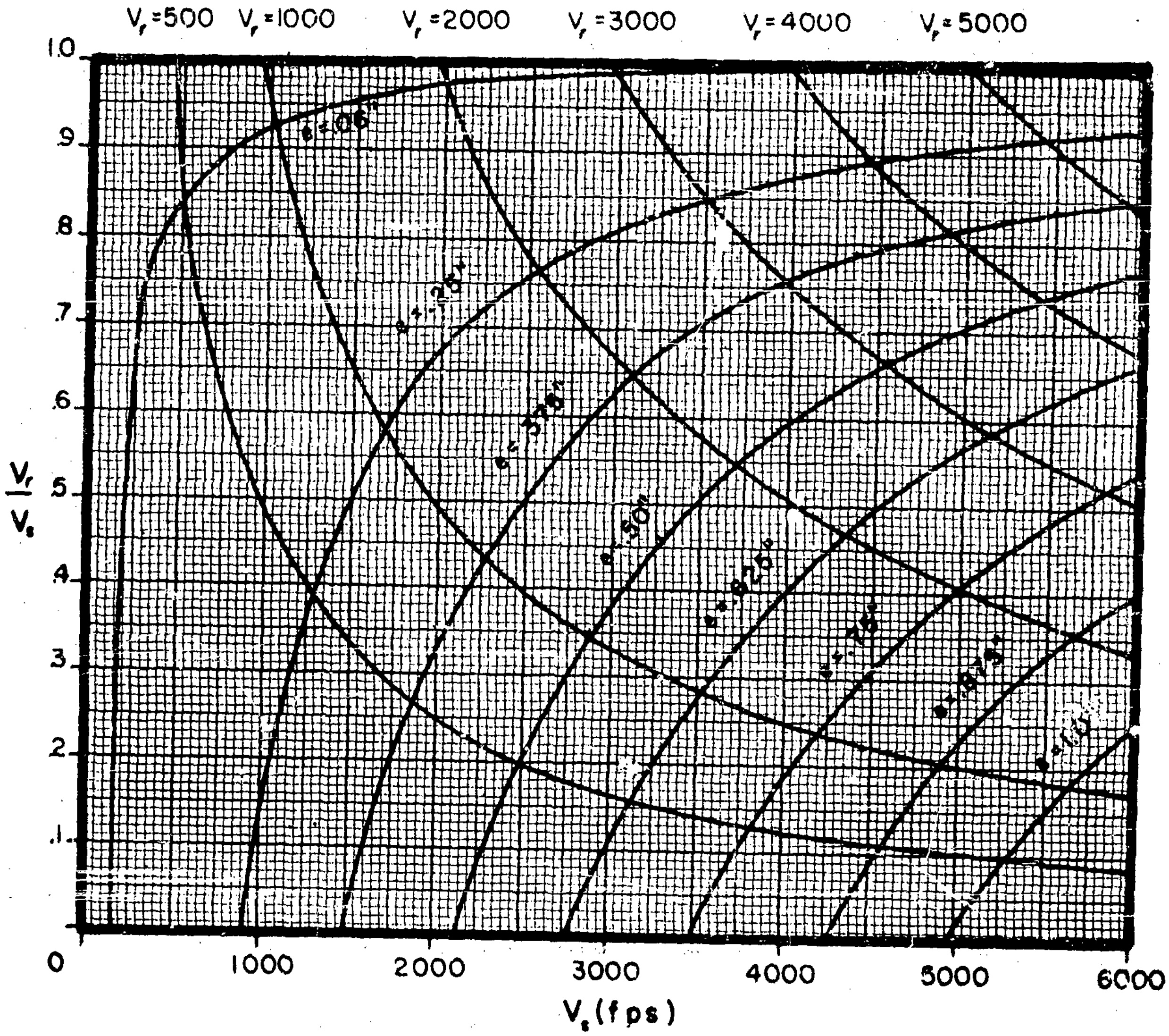
Fragment:
Type: BRL Pre-formed
Material: Tungsten Alloy
Size: 100 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B~100)
Obliquity: 0°

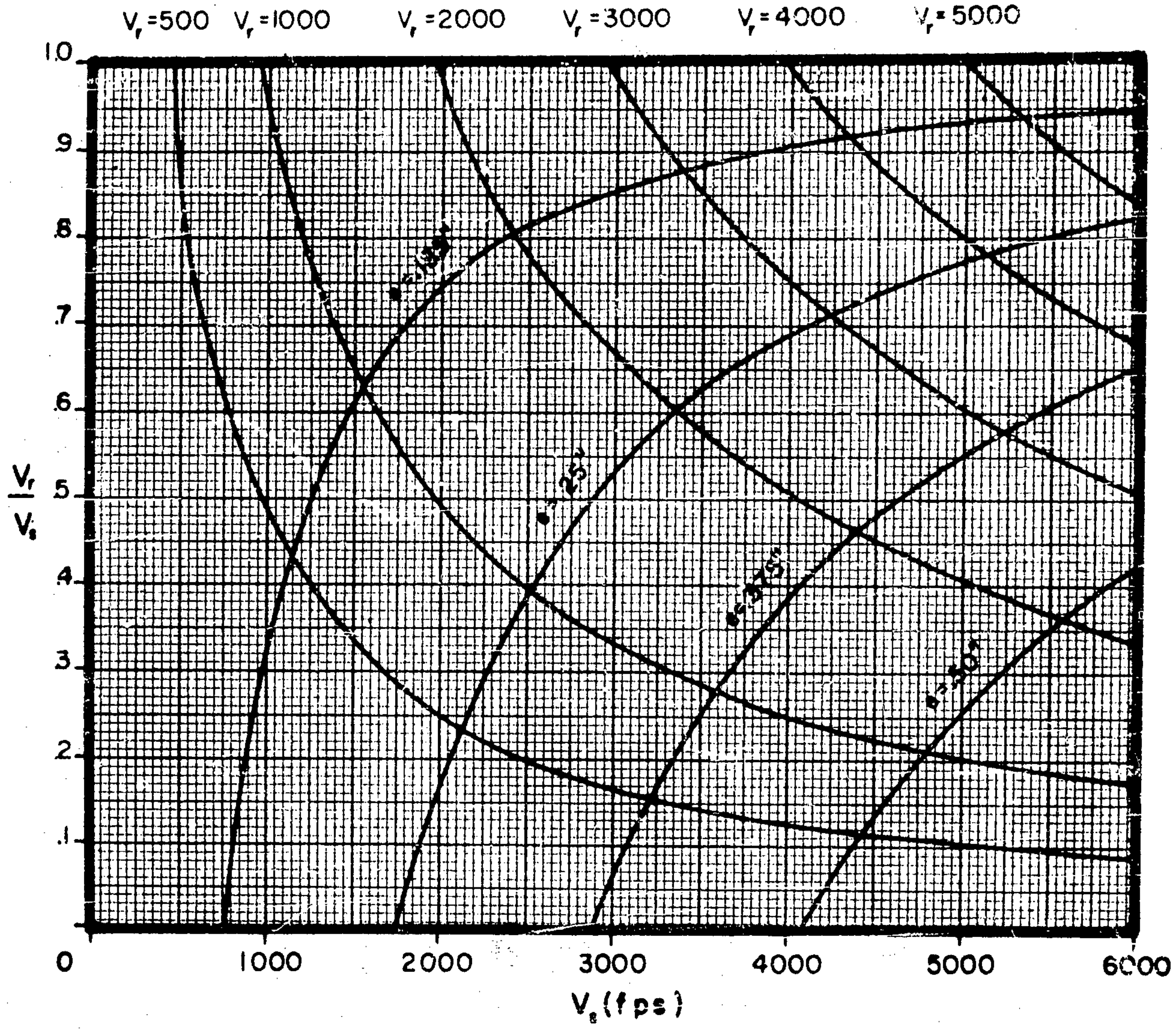
Fragment:
Type: BRL Pre-formed
Material: Tungsten Alloy
Size: 300 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B~100)
Obliquity: 60°

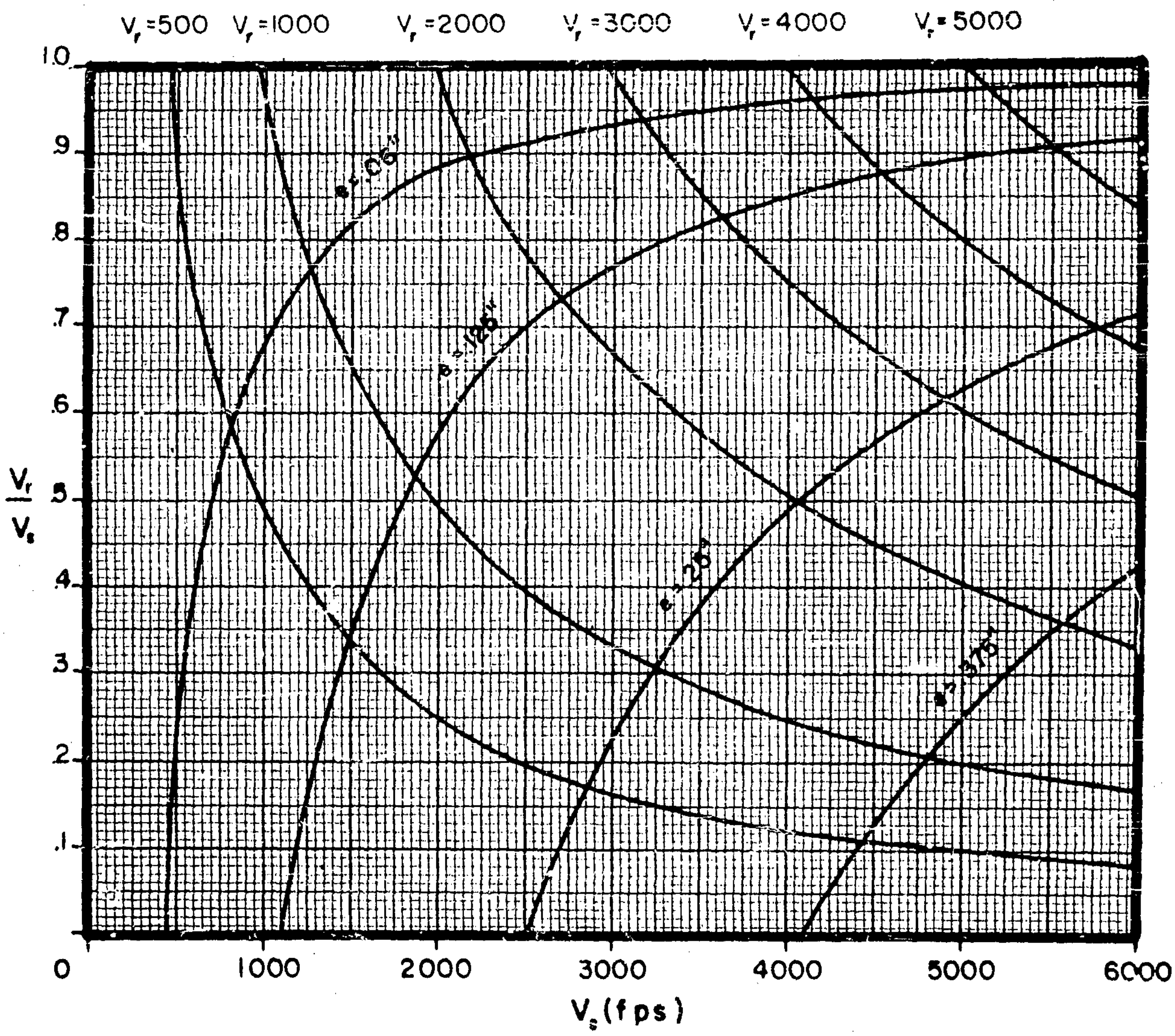
Fragment:
Type: BRL Pre-formed
Material: Tungsten Alloy
Size: 300 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B~100)
Obliquity: 70°

Fragment:
Type: BRL Pre-formed
Material: Tungsten Alloy
Size: 300 grains



APPENDIX V

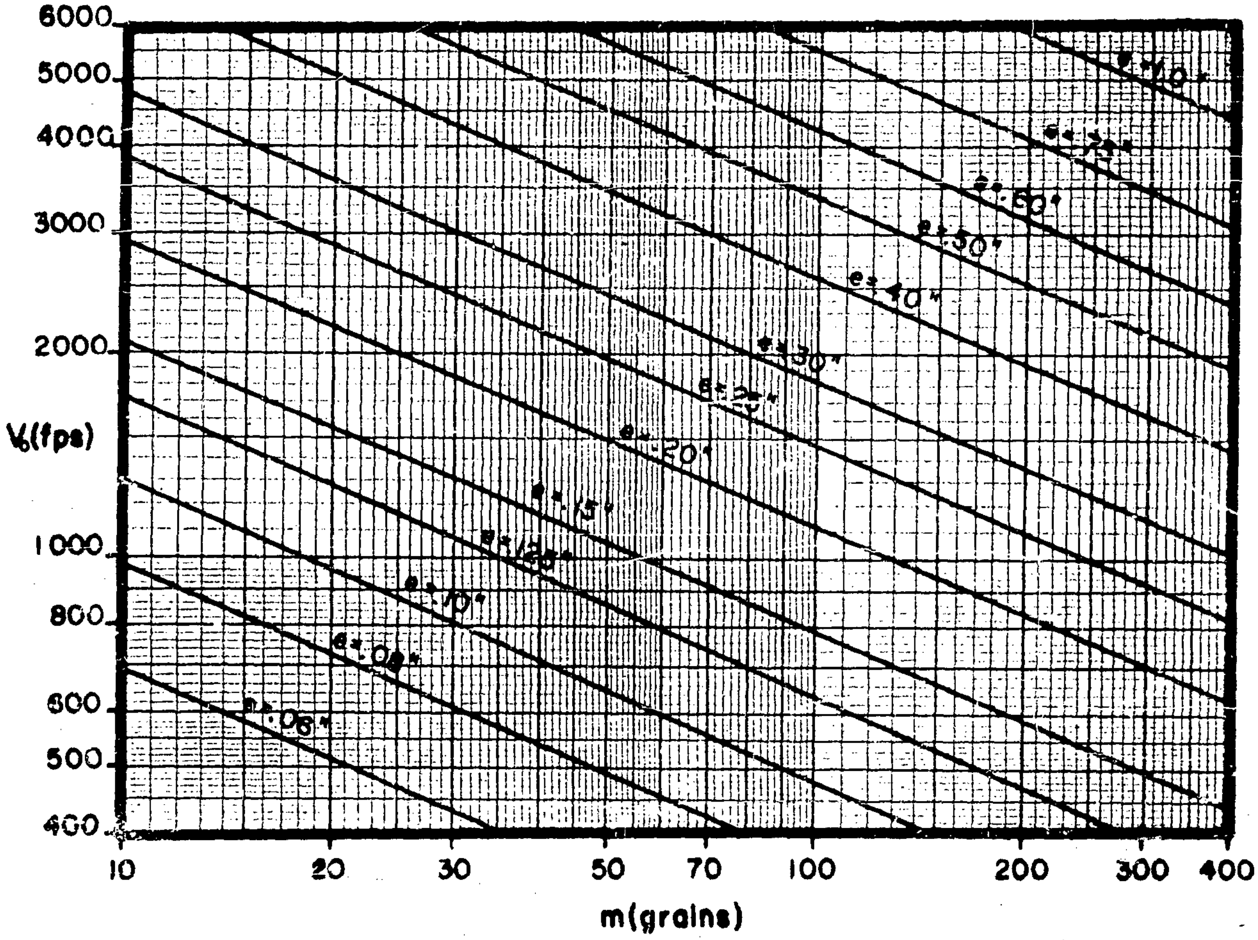
Tungsten Alloy Fragments vs Steel Plate (B ~ 100)

B. V_o vs Fragment Weight for Selected Plate Thicknesses

Vo vs Fragment Weight for Selected Plate Thicknesses

Plate Material: Steel (B~100)
Obliquity: 0°

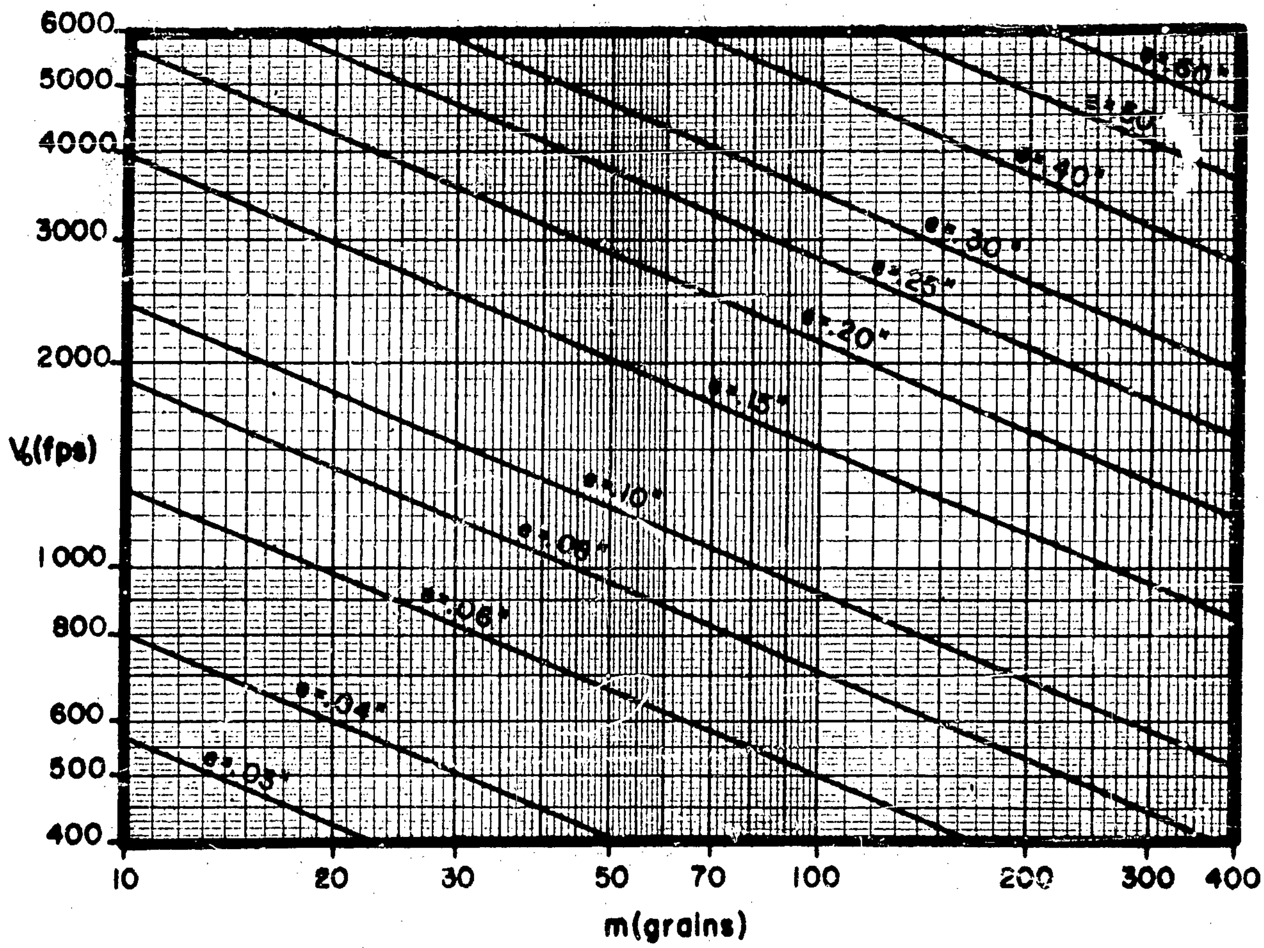
Fragment:
Type: B R L Pre-formed
Material: Tungsten Alloy



V_o vs Fragment Weight for Selected Plate Thicknesses

Plate Material: Steel (B~100)
Obliquity: 60°

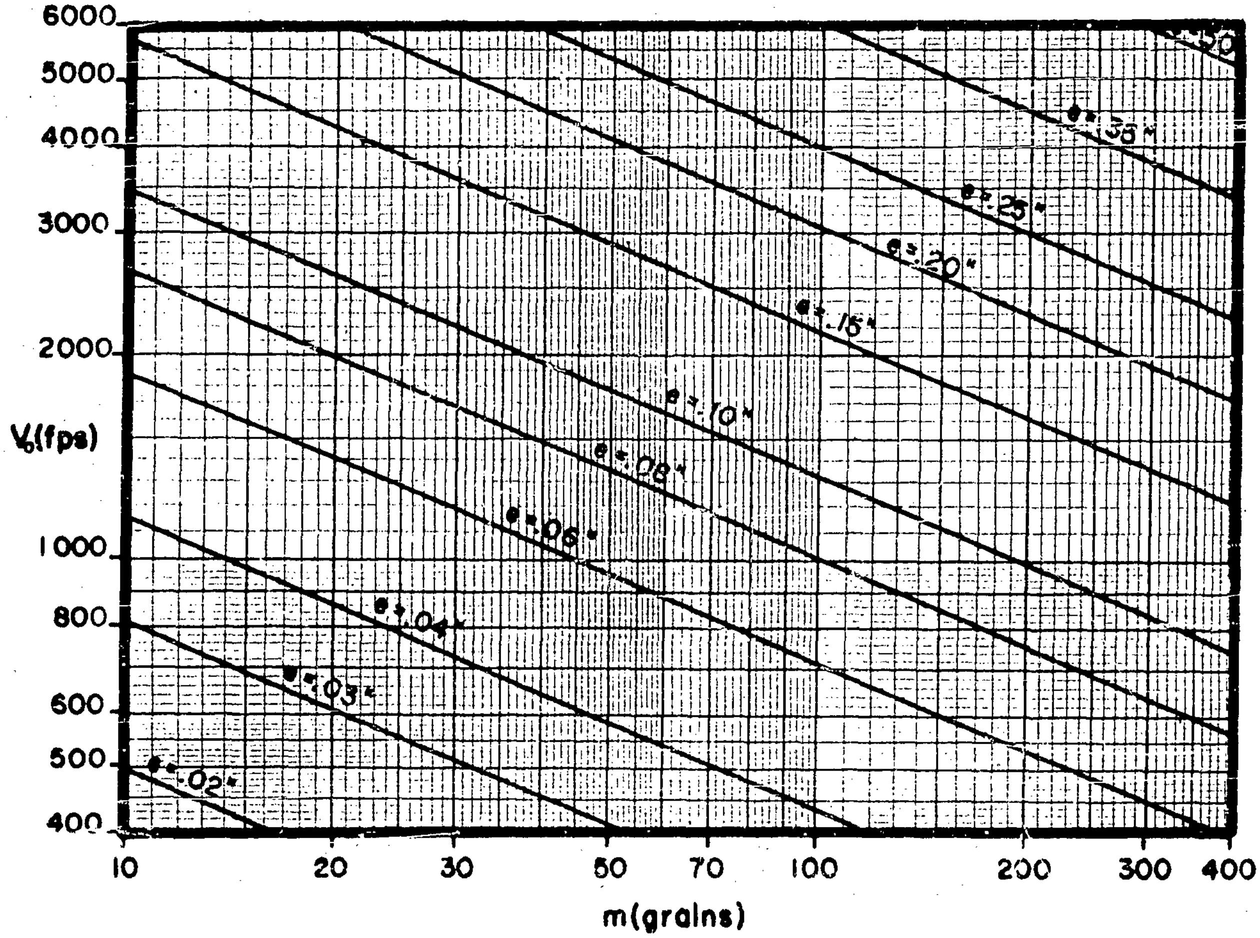
Fragment:
Type: B R L Pre-formed
Material: Tungsten Alloy



V_o vs Fragment Weight for Selected Plate Thicknesses

Plate Material: Steel (B ~100)
Obliquity: 70°

Fragment:
Type: B R L Pre-formed
Material: Tungsten Alloy



APPENDIX VI

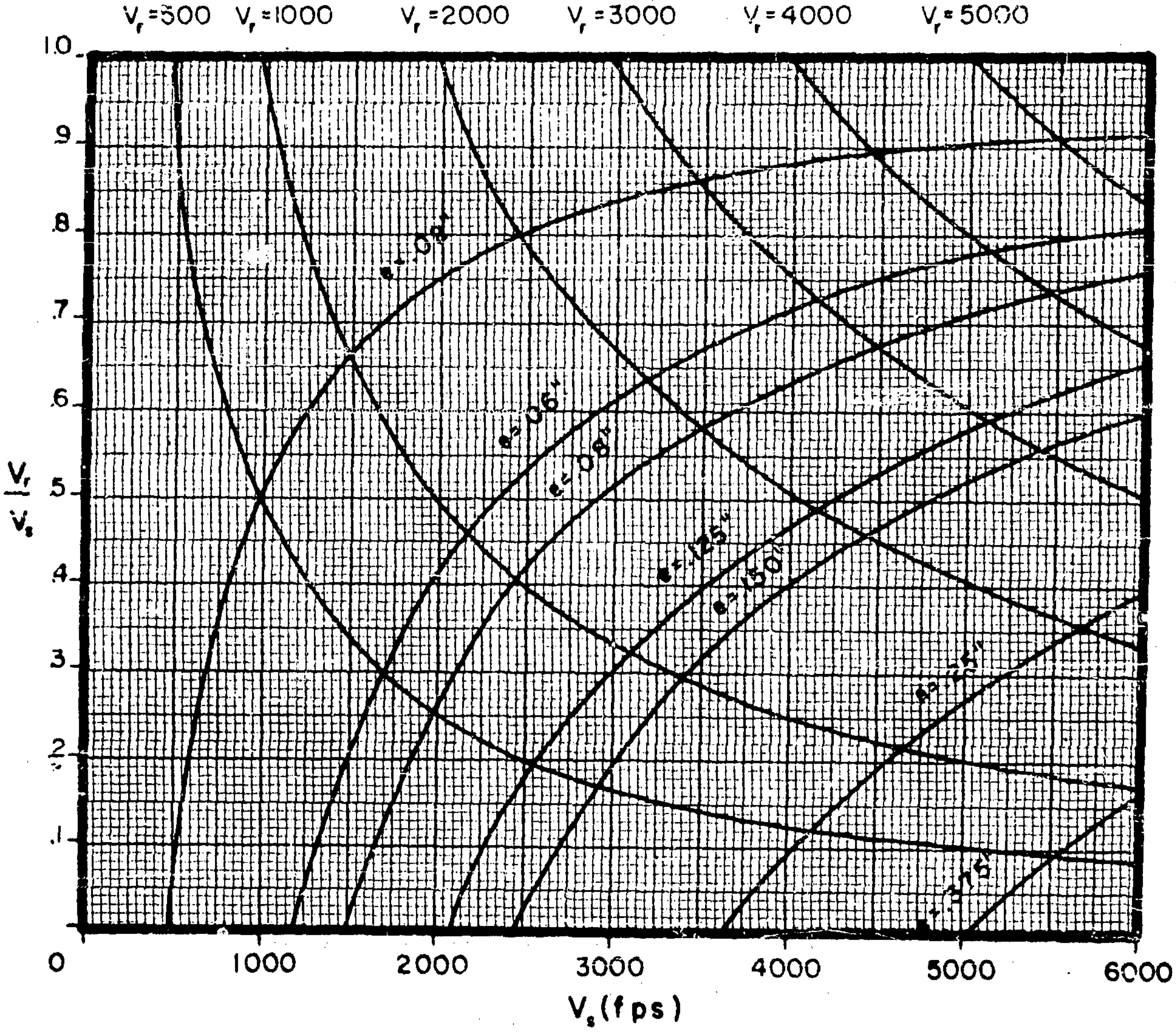
Tungsten Alloy Fragments vs Steel Plate (B ~ 300)

A. Residual Velocity/Striking Velocity vs Striking Velocity for Selected Plate Thicknesses

$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B~300)
Obliquity: 0°

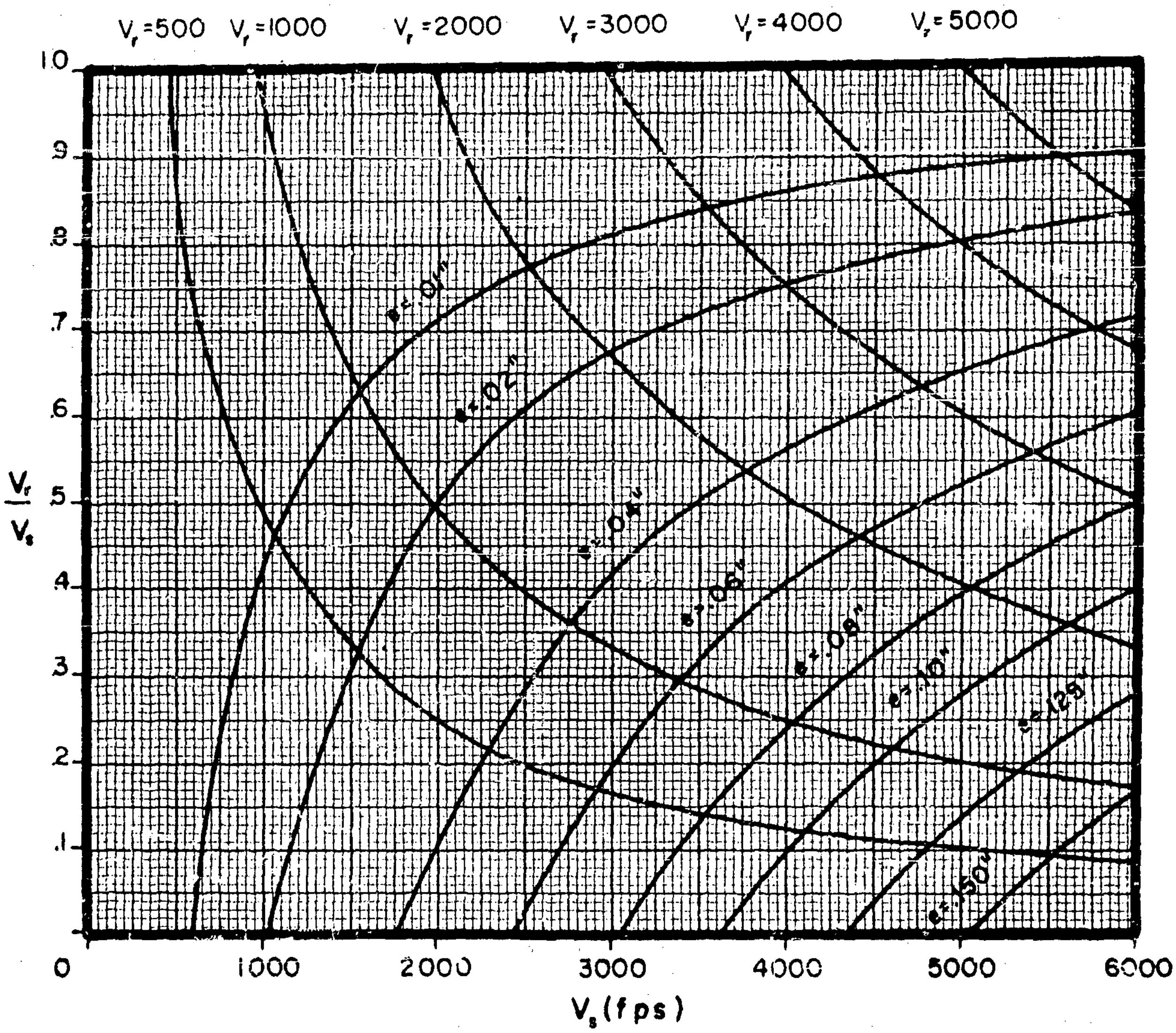
Fragment:
Type: BRL Pre-formed
Material: Tungsten Alloy
Size: 30 grains



Residual Velocity / Striking Velocity vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B~300)
Obliquity: 60°

Fragment:
Type: BRL Pre-formed
Material: Tungsten Alloy
Size: 30 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B~300)

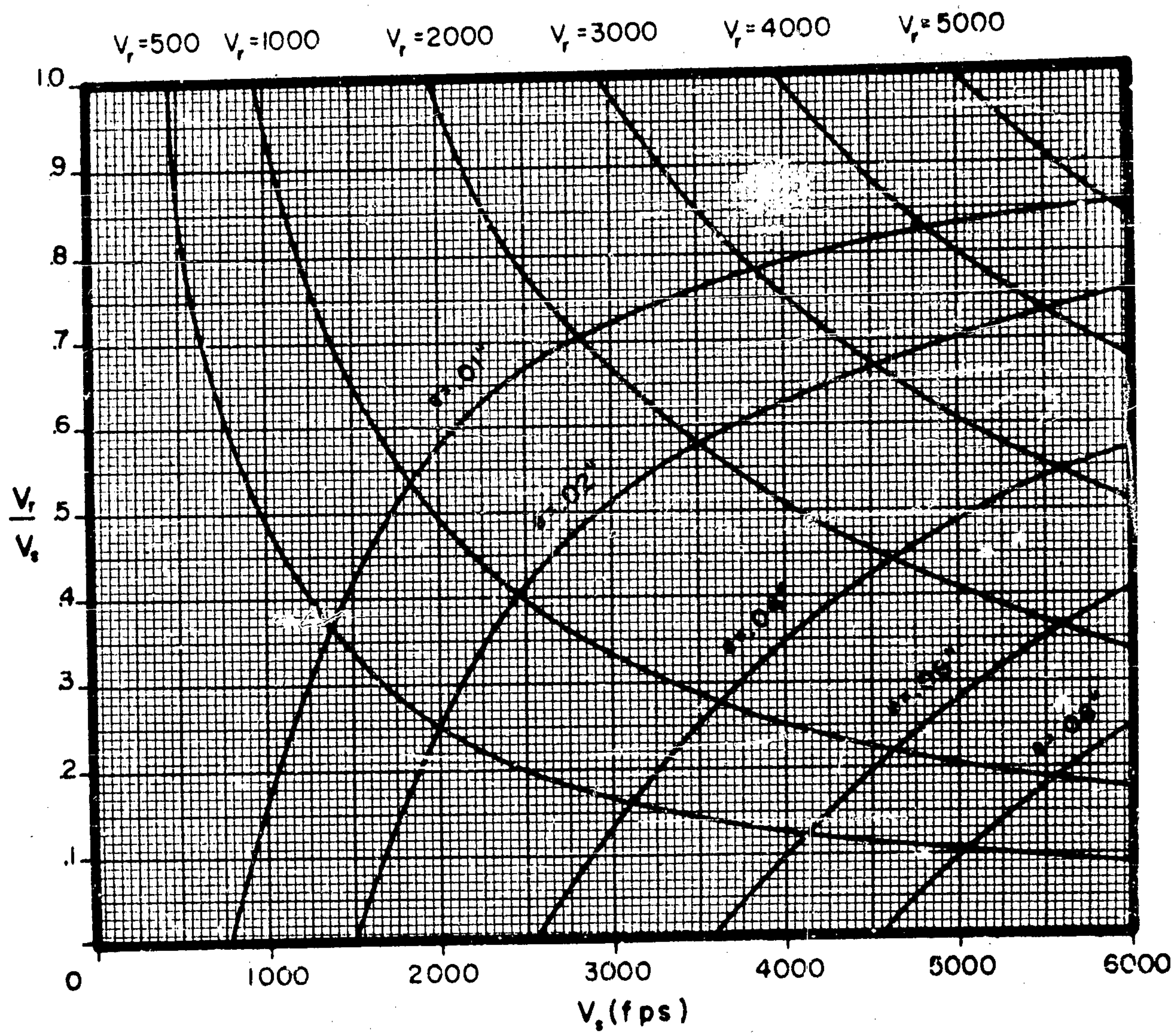
Obliquity: 70°

Fragment:

Type: BRL Pre-formed

Material: Tungsten Alloy

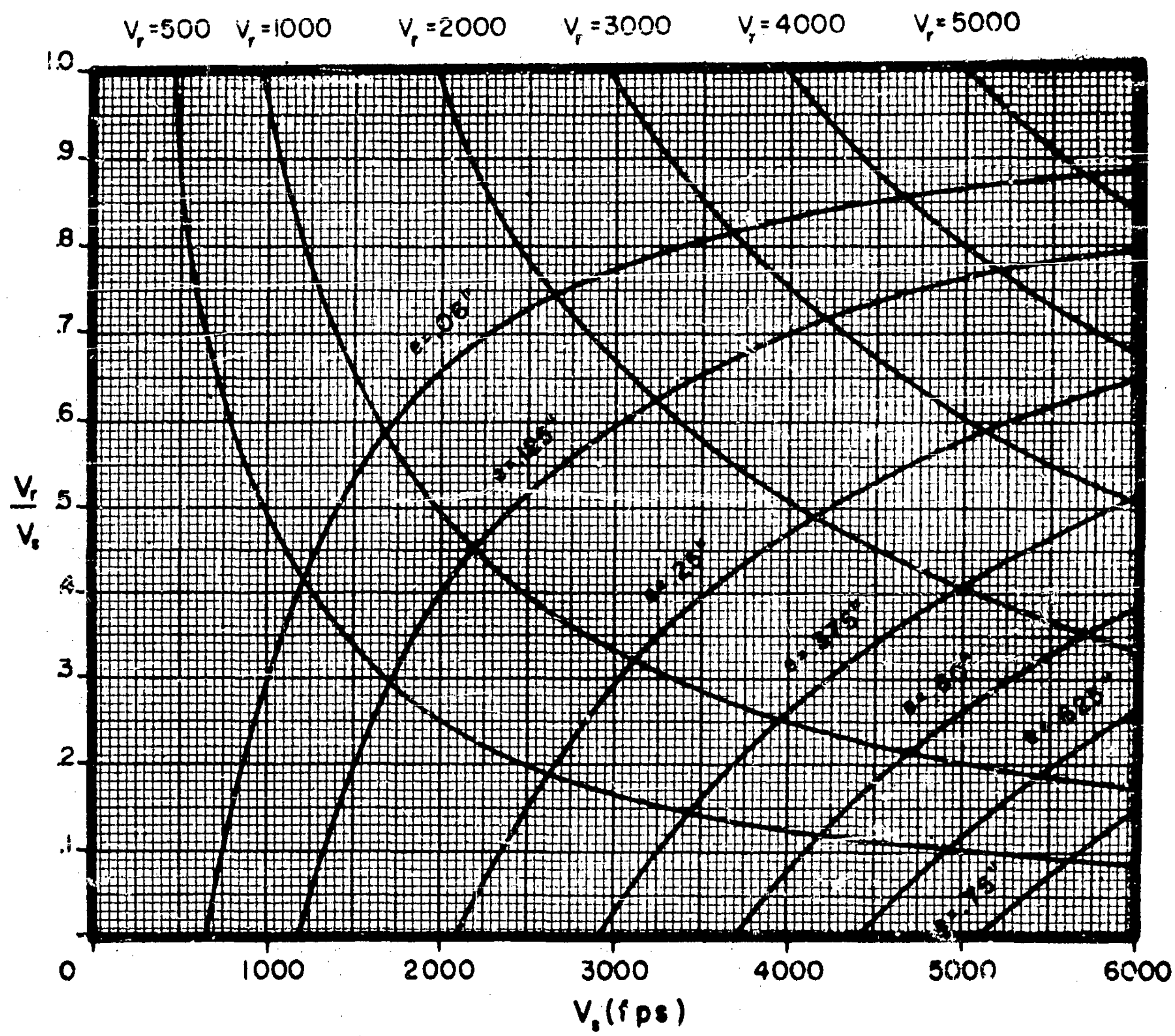
Size: 30 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B~300)
Obliquity: 0°

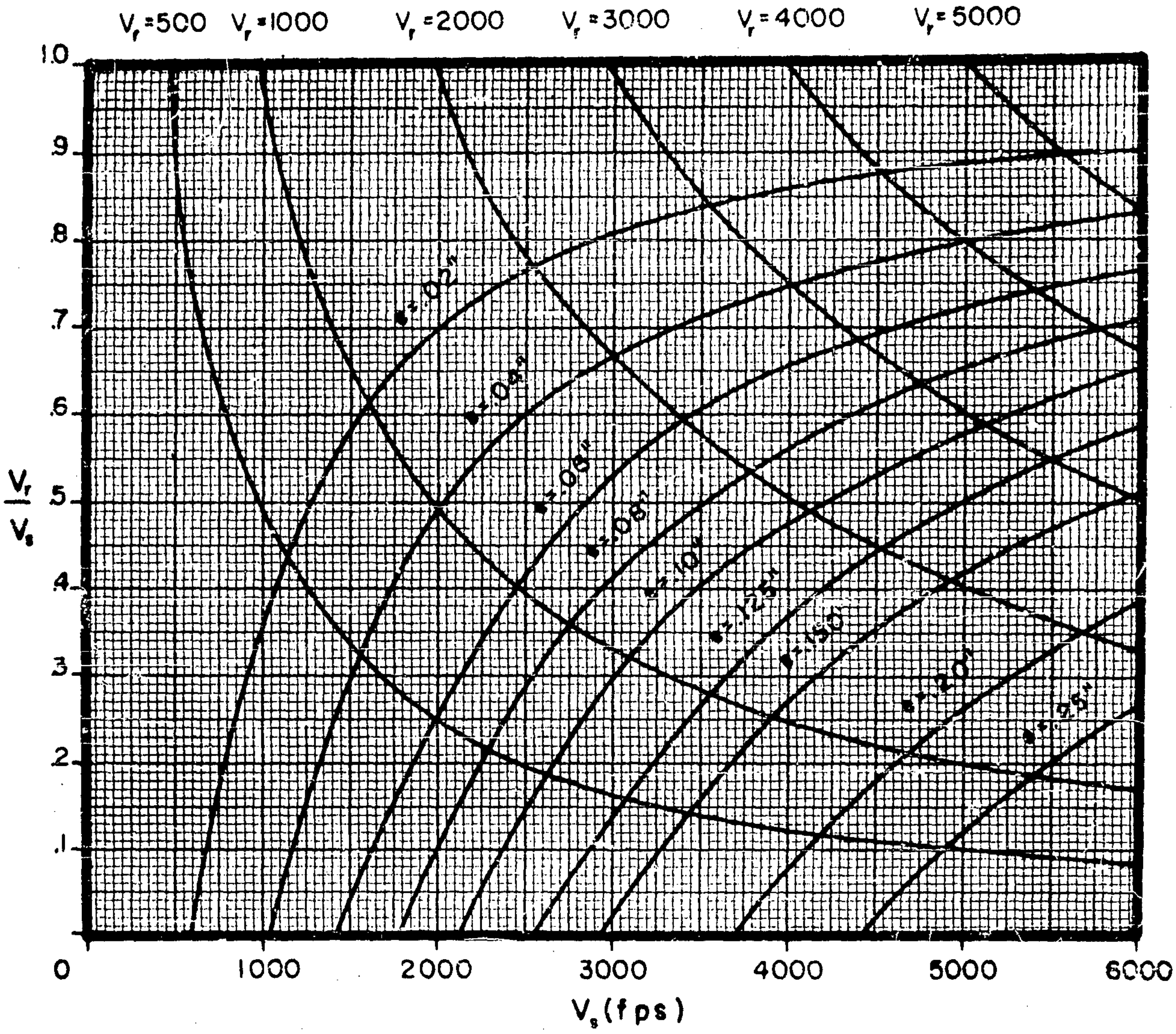
Fragment:
Type: BRL Pre-formed
Material: Tungsten Alloy
Size: 100 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B~300)
Obliquity: 60°

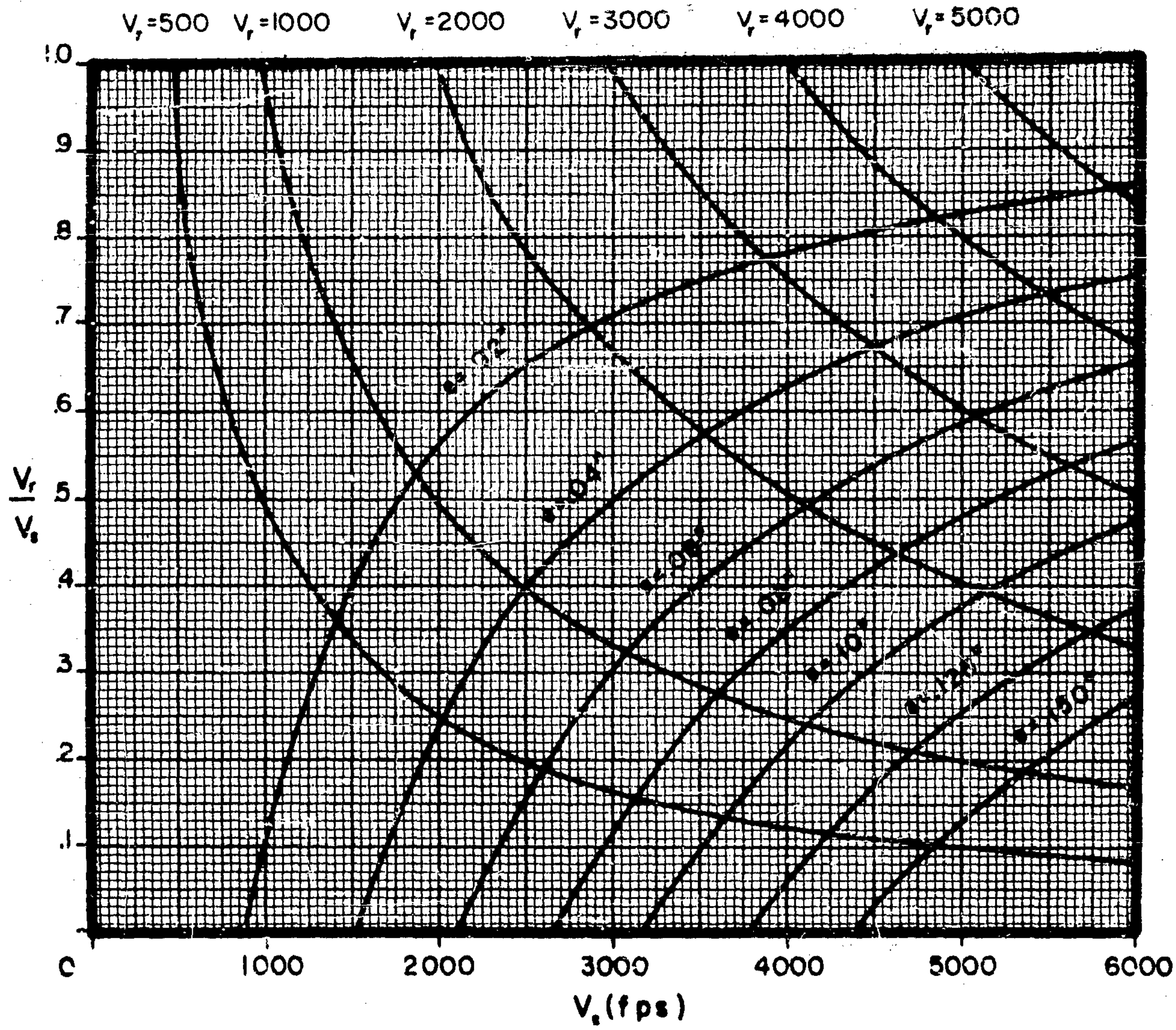
Fragment:
Type: BRL Pre-formed
Material: Tungsten Alloy
Size: 100 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B~300)
Obliquity: 70°

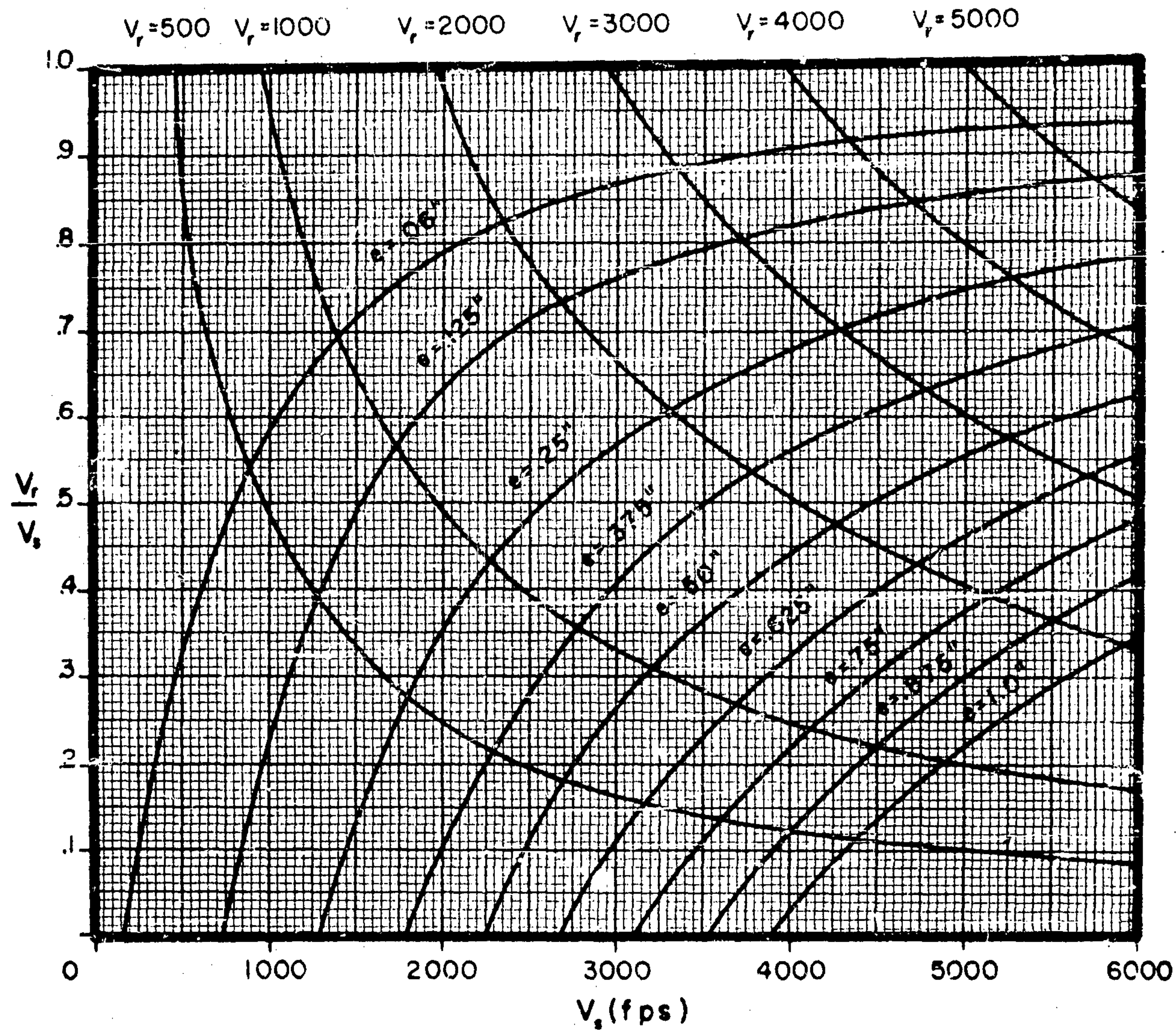
Fragment:
Type: BRL Pre-formed
Material: Tungsten Alloy
Size: 100 grains



Residual Velocity / Striking Velocity vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B~300)
Obliquity: 0°

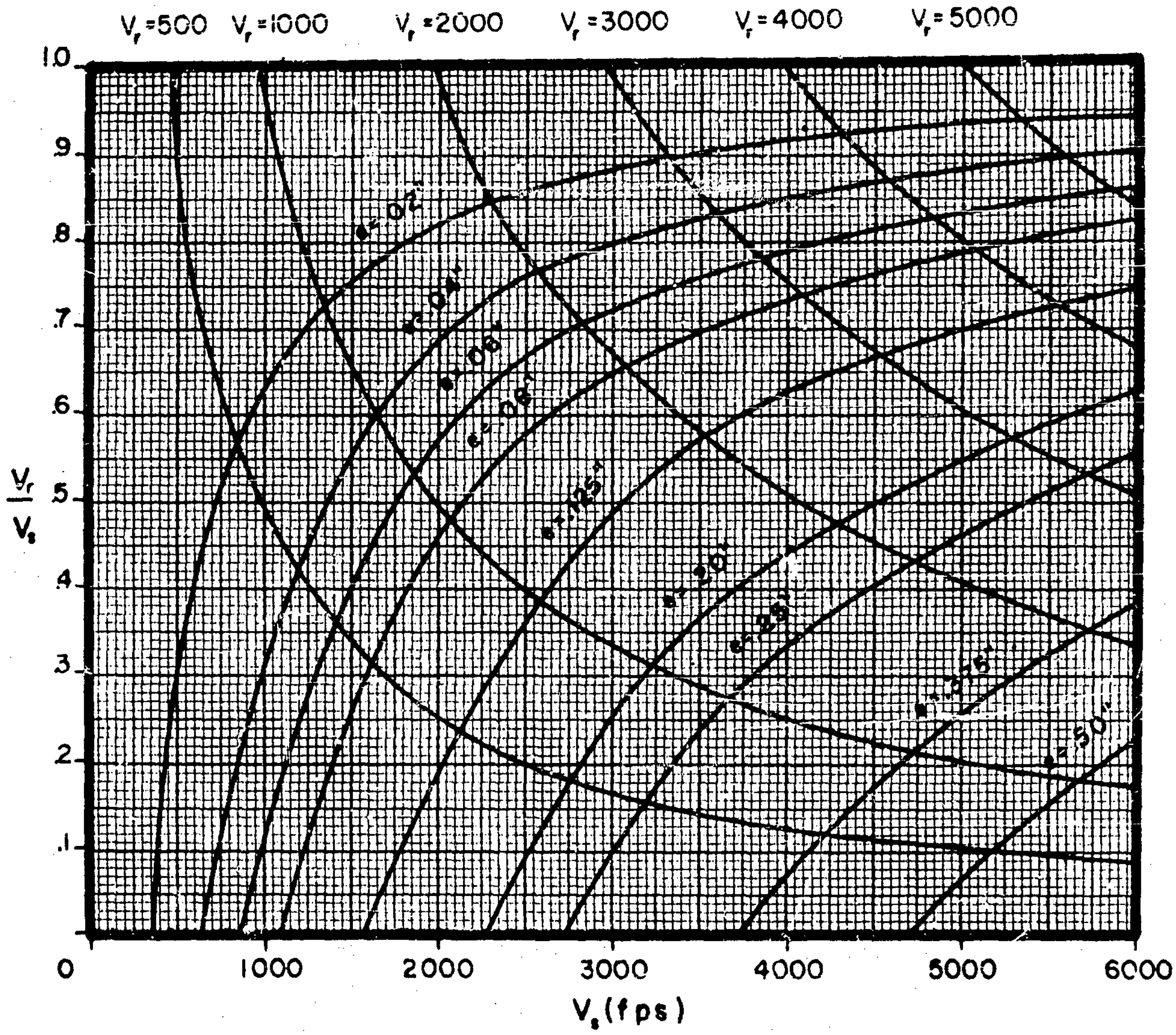
Fragment:
Type: BRL Pre-formed
Material: Tungsten Alloy
Size: 300 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B~300)
Obliquity: 60°

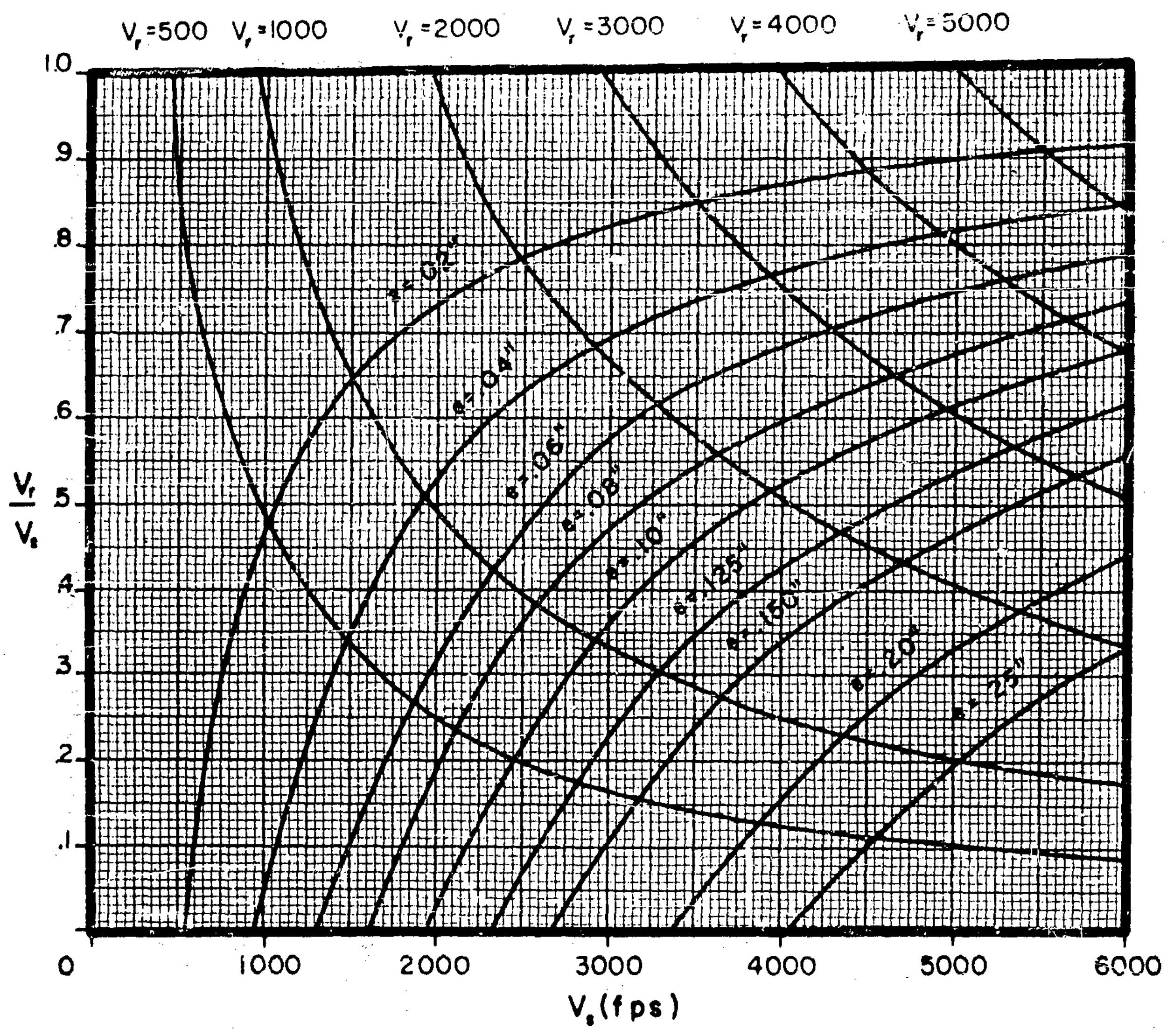
Fragment:
Type: BRL Pre-formed
Material: Tungsten Alloy
Size: 300 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B~300)
Obliquity: 70°

Fragment:
Type: BRL Pre-formed
Material: Tungsten Alloy
Size: 300 grains



APPENDIX VI

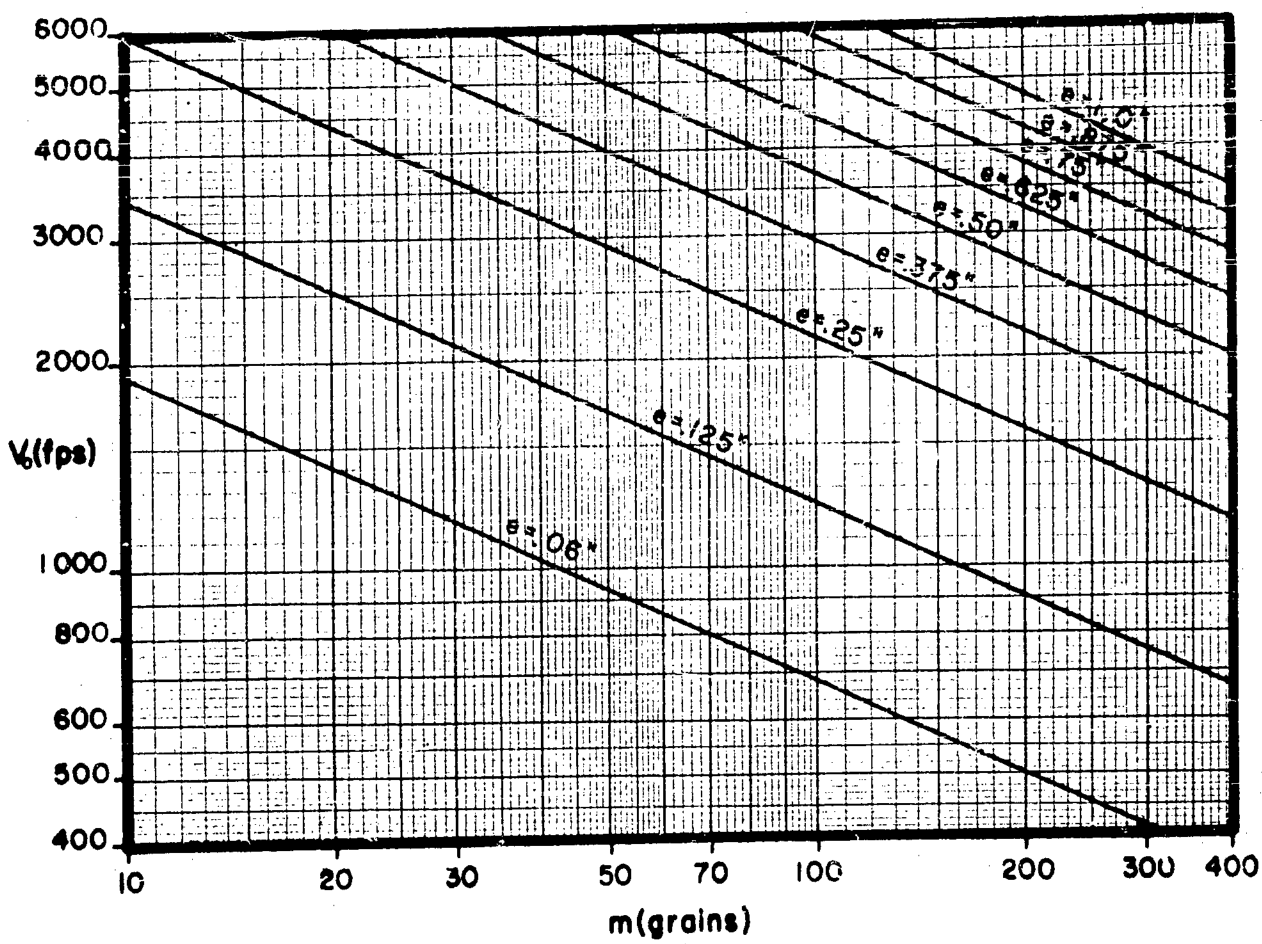
Tungsten Alloy Fragments vs Steel Plate (B ~ 300)

B. V_o vs Fragment Weight for Selected Plate Thicknesses

V_o vs Fragment Weight for Selected Plate Thicknesses

Plate Material: Steel (B ~ 300)
Obliquity: 0°

Fragment:
Type: B R L Pre-formed
Material: Tungsten Alloy



Vₒ vs Fragment Weight for Selected Plate Thicknesses

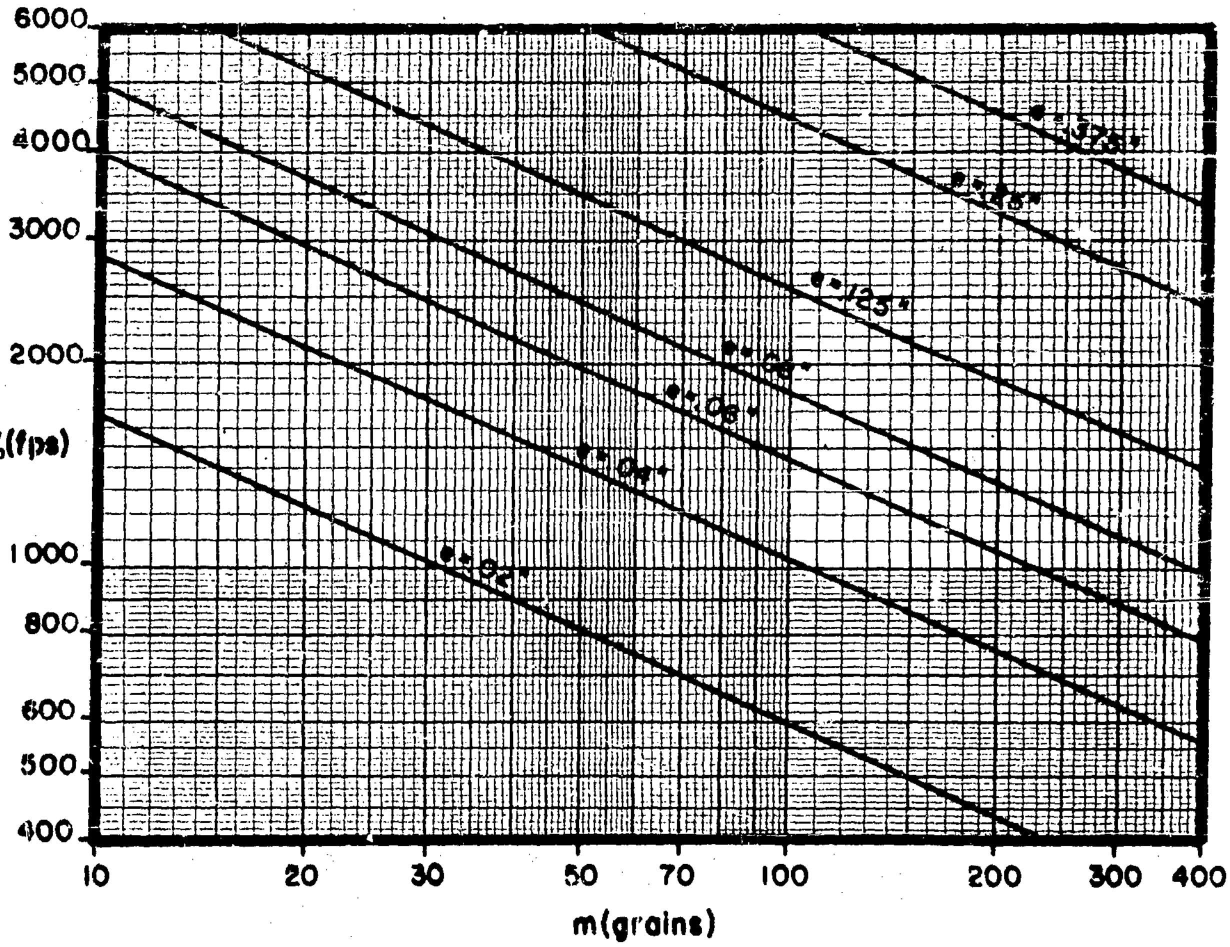
Plate Material: Steel (B~300)

Obliquity: 60°

Fragment:

Type: B R L Pre-formed

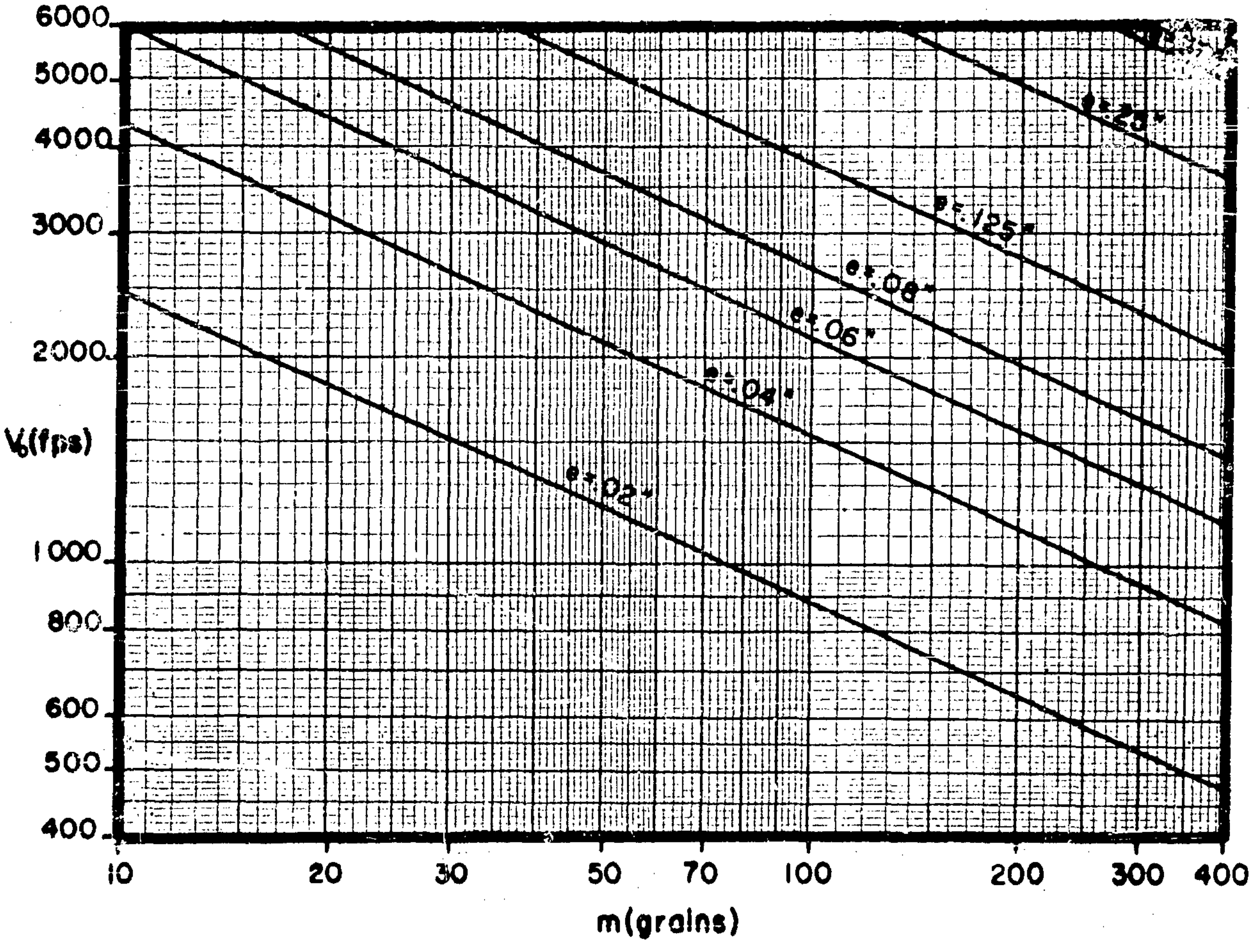
Material: Tungsten Alloy



V_o vs Fragment Weight for Selected Plate Thicknesses

Plate Material: Steel (B ~ 300)
Obliquity: 70°

Fragment:
Type: B R L Pre-formed
Material: Tungsten Alloy



APPENDIX VII

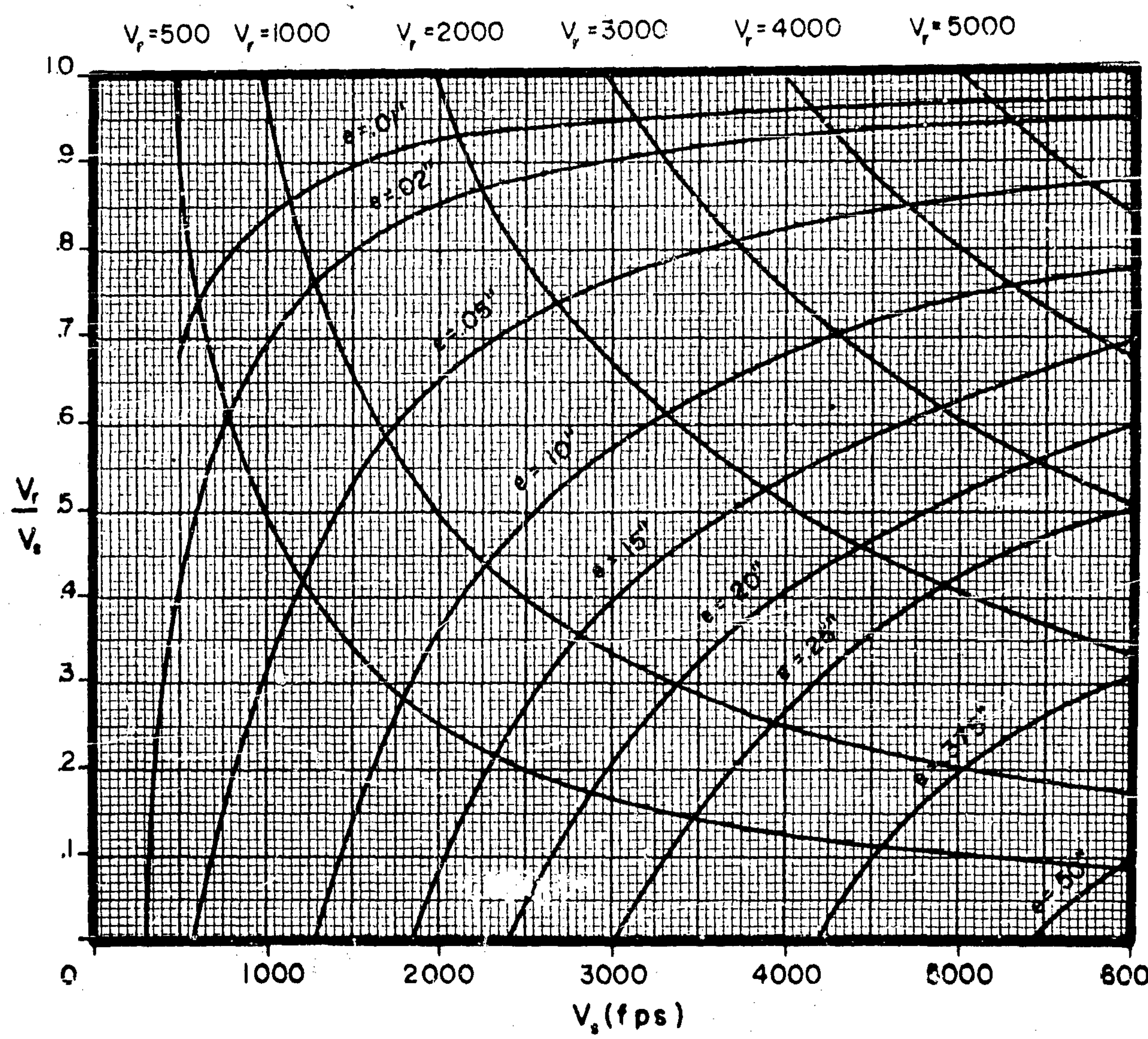
Steel Fragments vs Steel Plate

A. Residual Velocity/Striking Velocity vs Striking Velocity for Selected Plate Thicknesses; B=100

$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B=100)
Obliquity: 0°

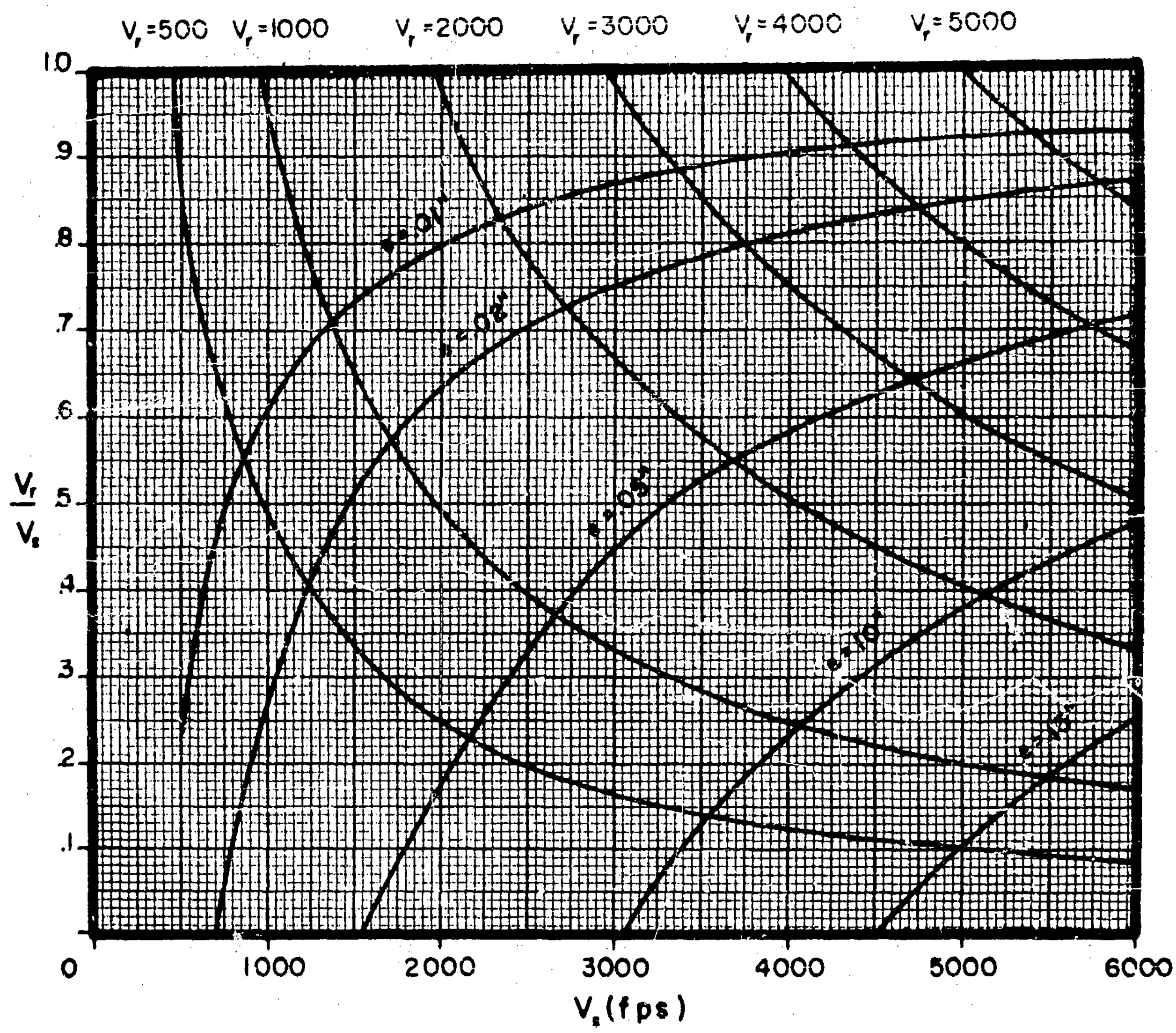
Fragment:
Type: BRL Pre-formed
Material: Steel
Size: 30 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B=100)
Obliquity: 60°

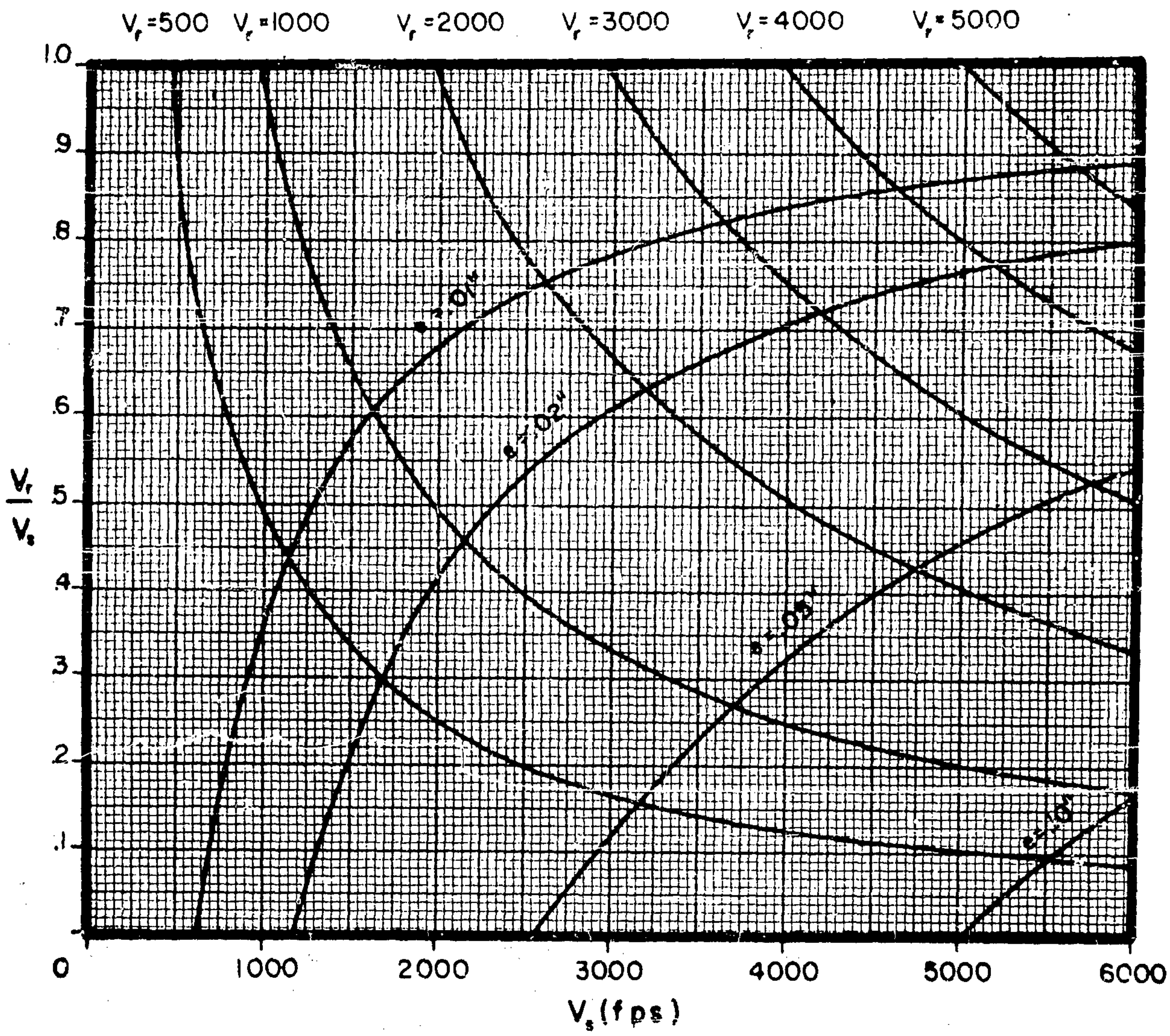
Fragment:
Type: BRL Pre-formed
Material: Steel
Size: 30 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B=100)
Obliquity: 70°

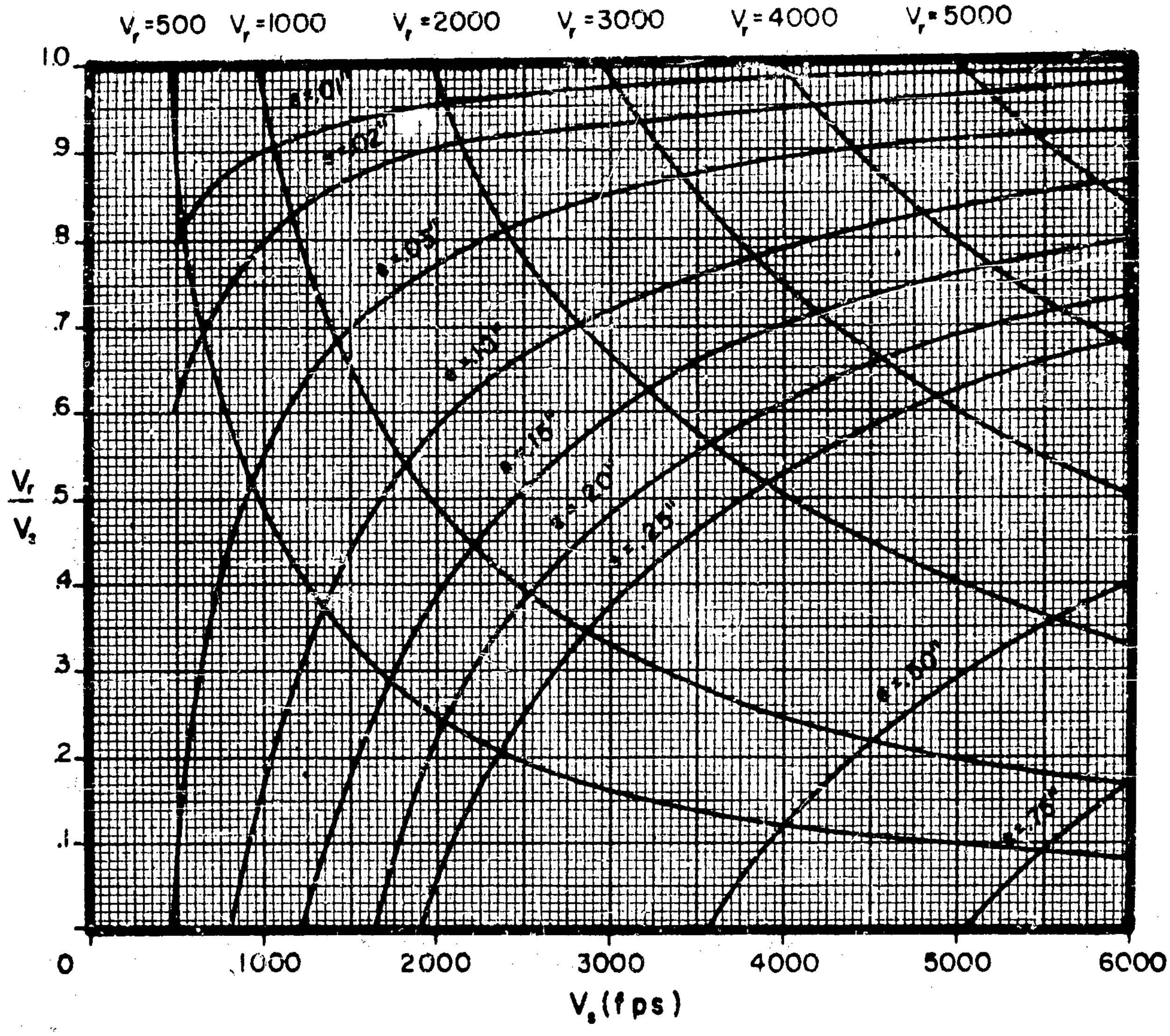
Fragment:
Type: BRL Pre-formed
Material: Steel
Size: 30 grains



Residual Velocity / Striking Velocity vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B=100)
Obliquity: 0°

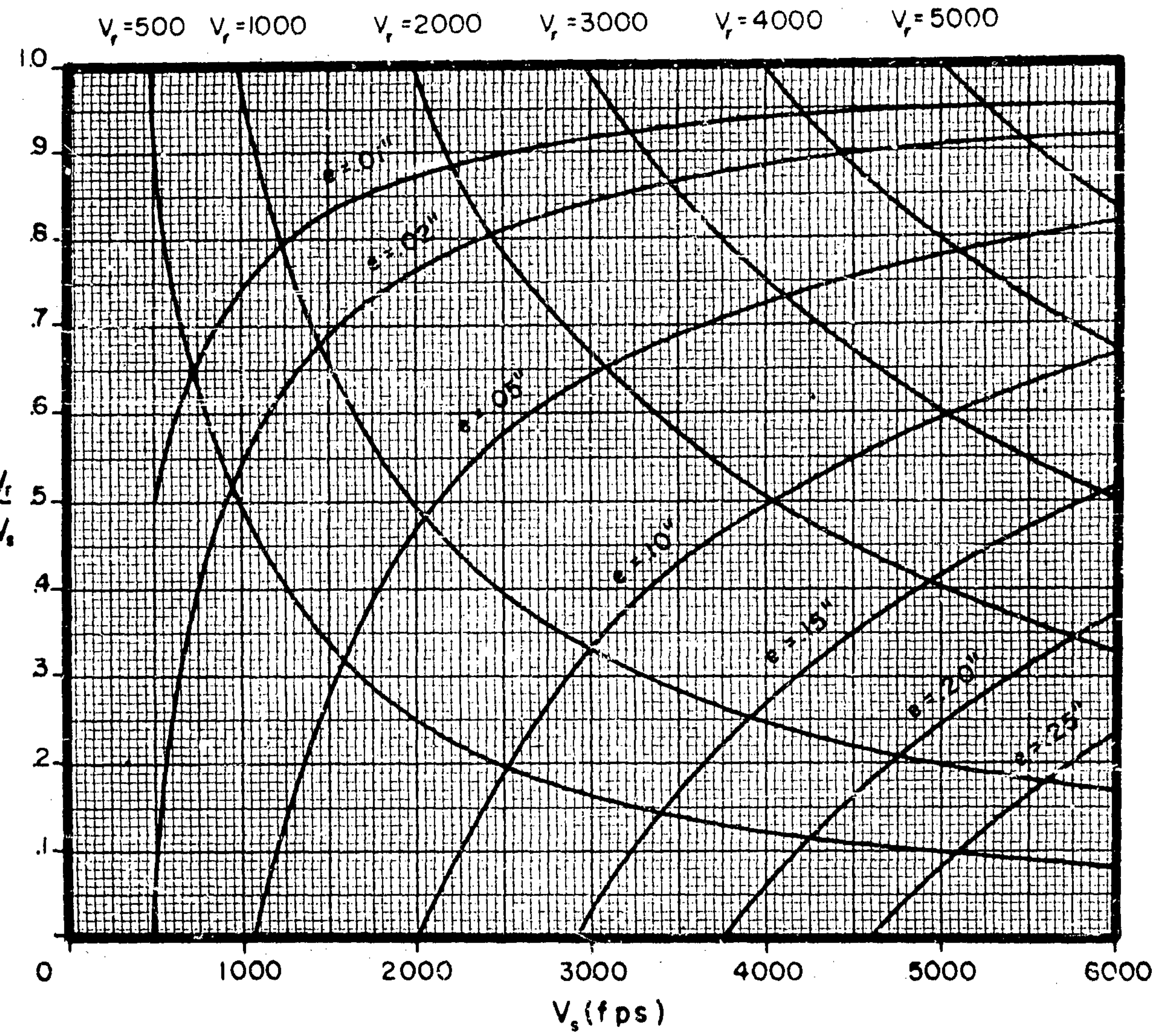
Fragment:
Type: BRL Pre-formed
Material: Steel
Size: 100 grains



Residual Velocity / Striking Velocity vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B=100)
Obliquity: 60°

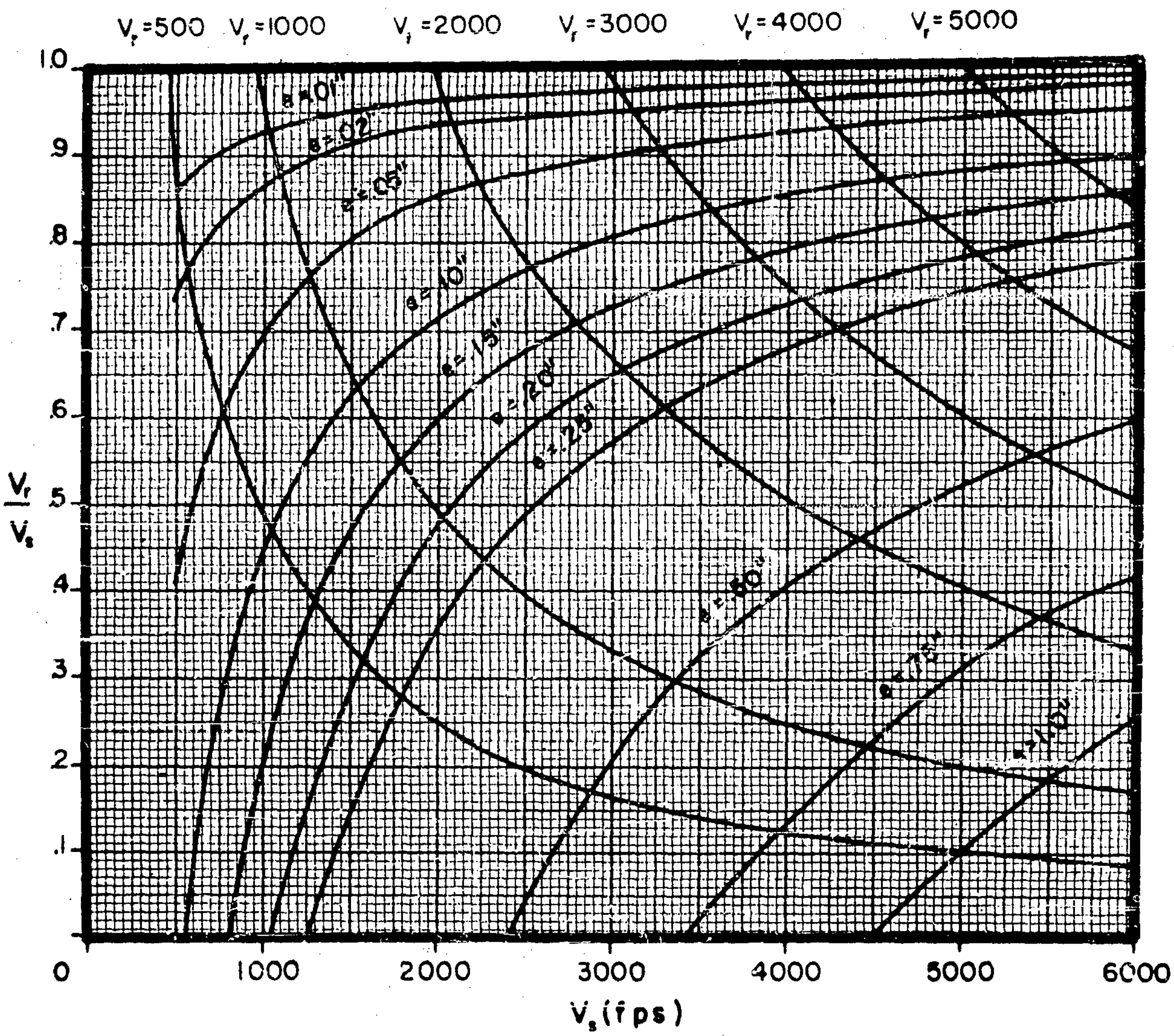
Fragment:
Type: BRL Pre-formed
Material: Steel
Size: 100 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B=100)
Obliquity: 0°

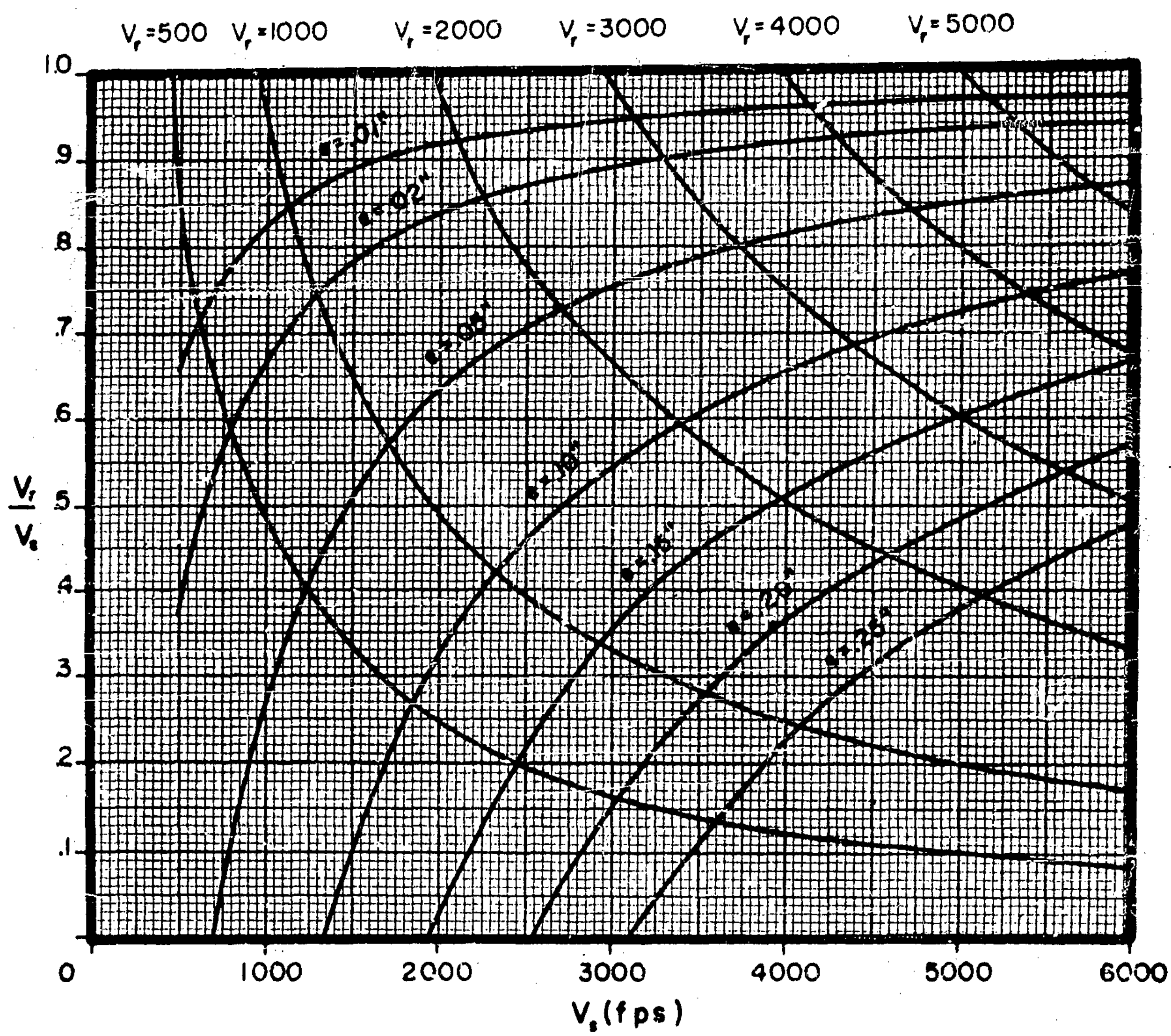
Fragment:
Type: BRL Pre-formed
Material: Steel
Size: 300 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B=100)
Obliquity: 60°

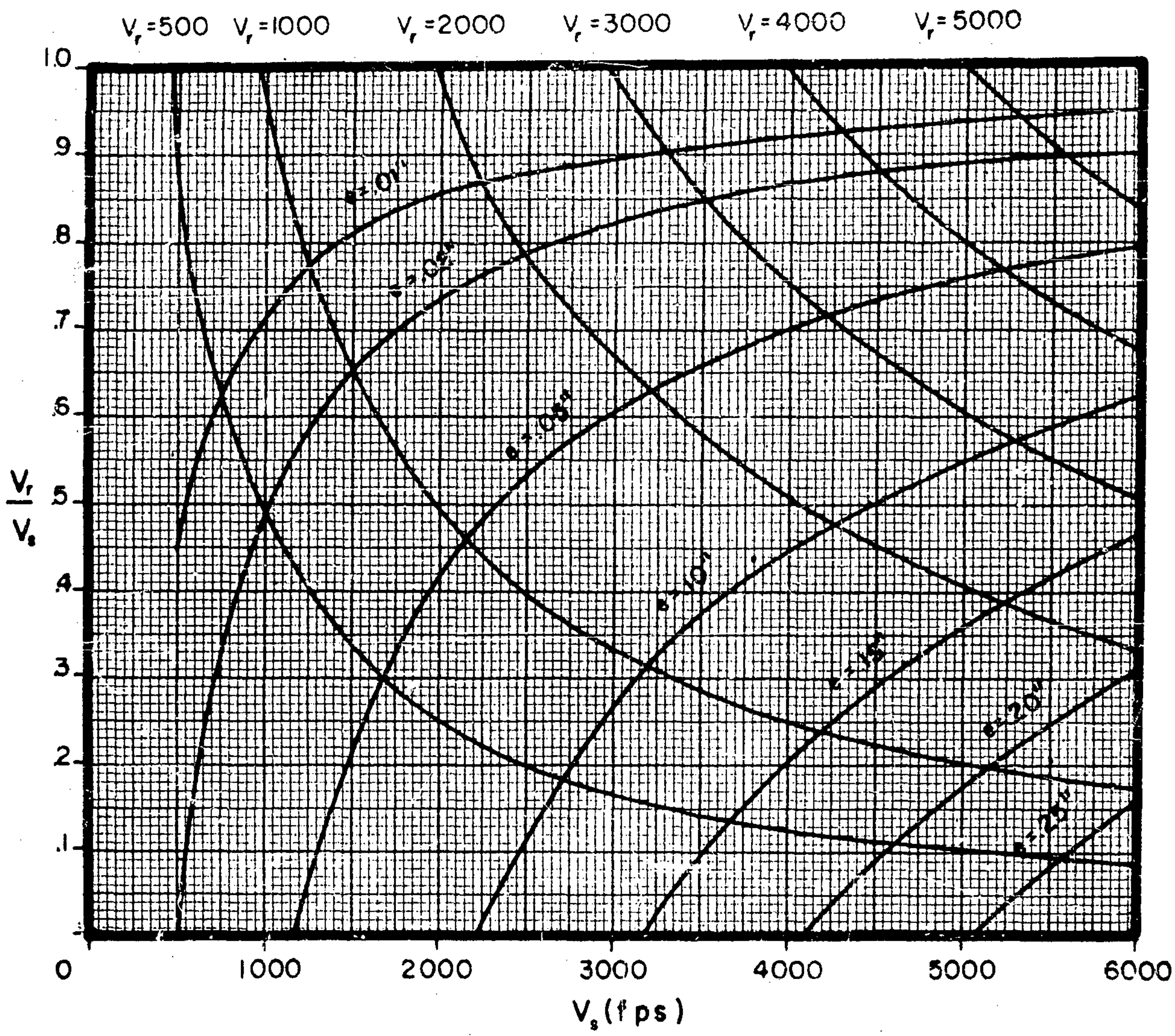
Fragment:
Type: BRL Pre-formed
Material: Steel
Size: 300 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B=100)
Obliquity: 70°

Fragment:
Type: BRL Pre-formed
Material: Steel
Size: 300 grains



APPENDIX VII

Steel Fragments vs Steel Plate

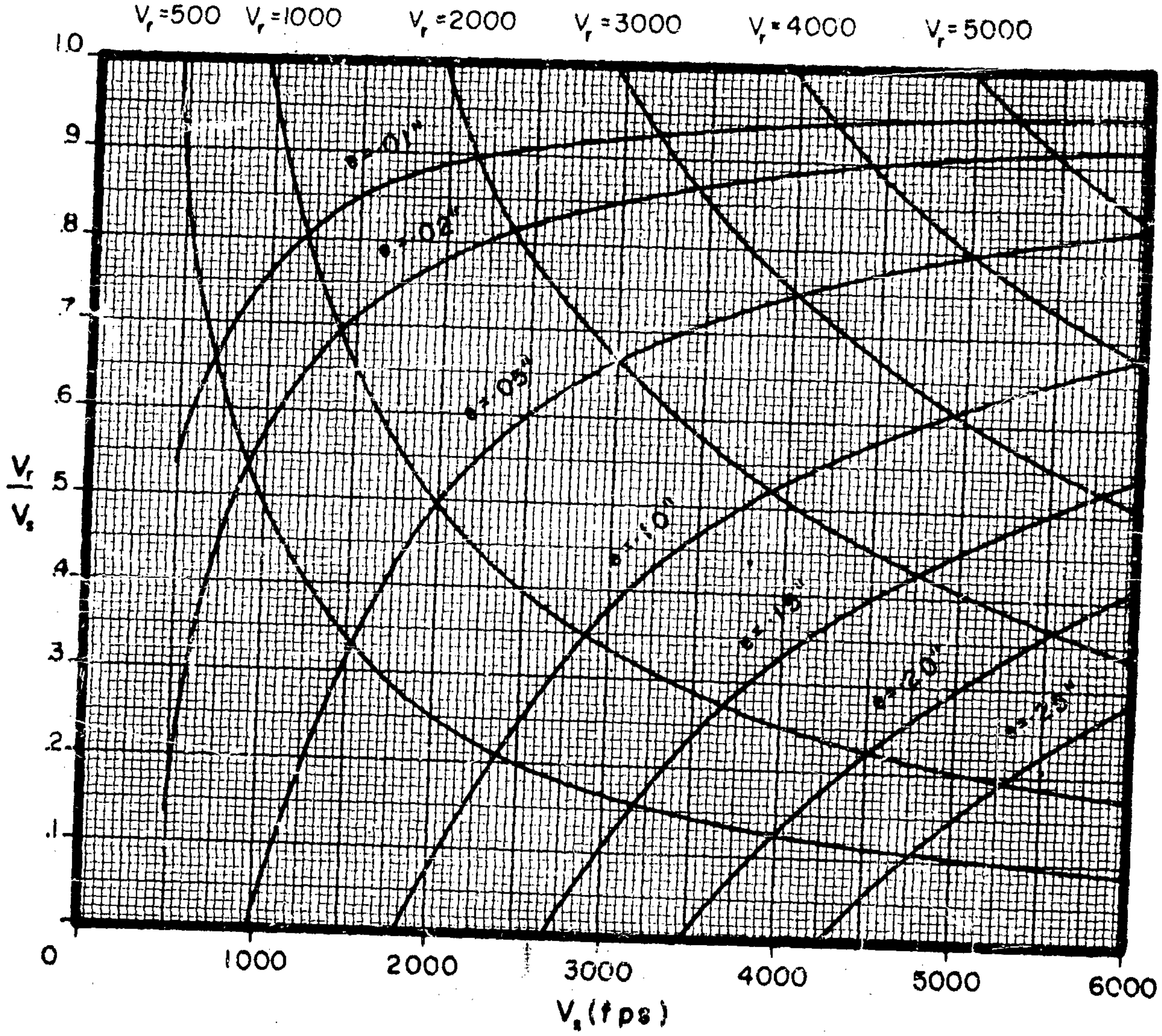
B. Residual Velocity/Striking Velocity vs Striking Velocity

for Selected Plate Thicknesses; B=300

Residual Velocity / Striking Velocity vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B=300)
Obliquity: 0°

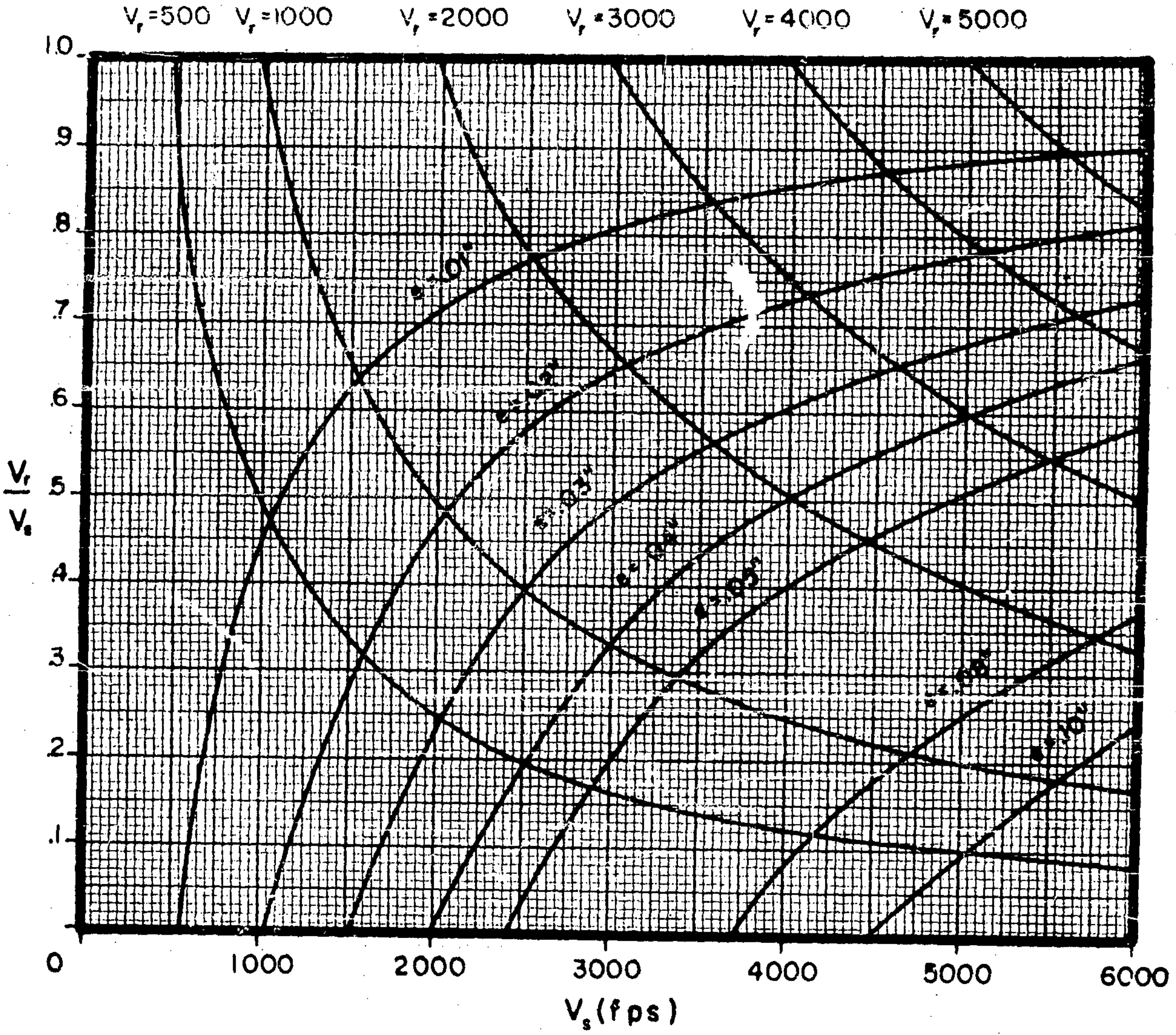
Fragment:
Type: BRL Pre-formed
Material: Steel
Size: 30 grains



Residual Velocity / Striking Velocity vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B=300)
Obliquity: 60°

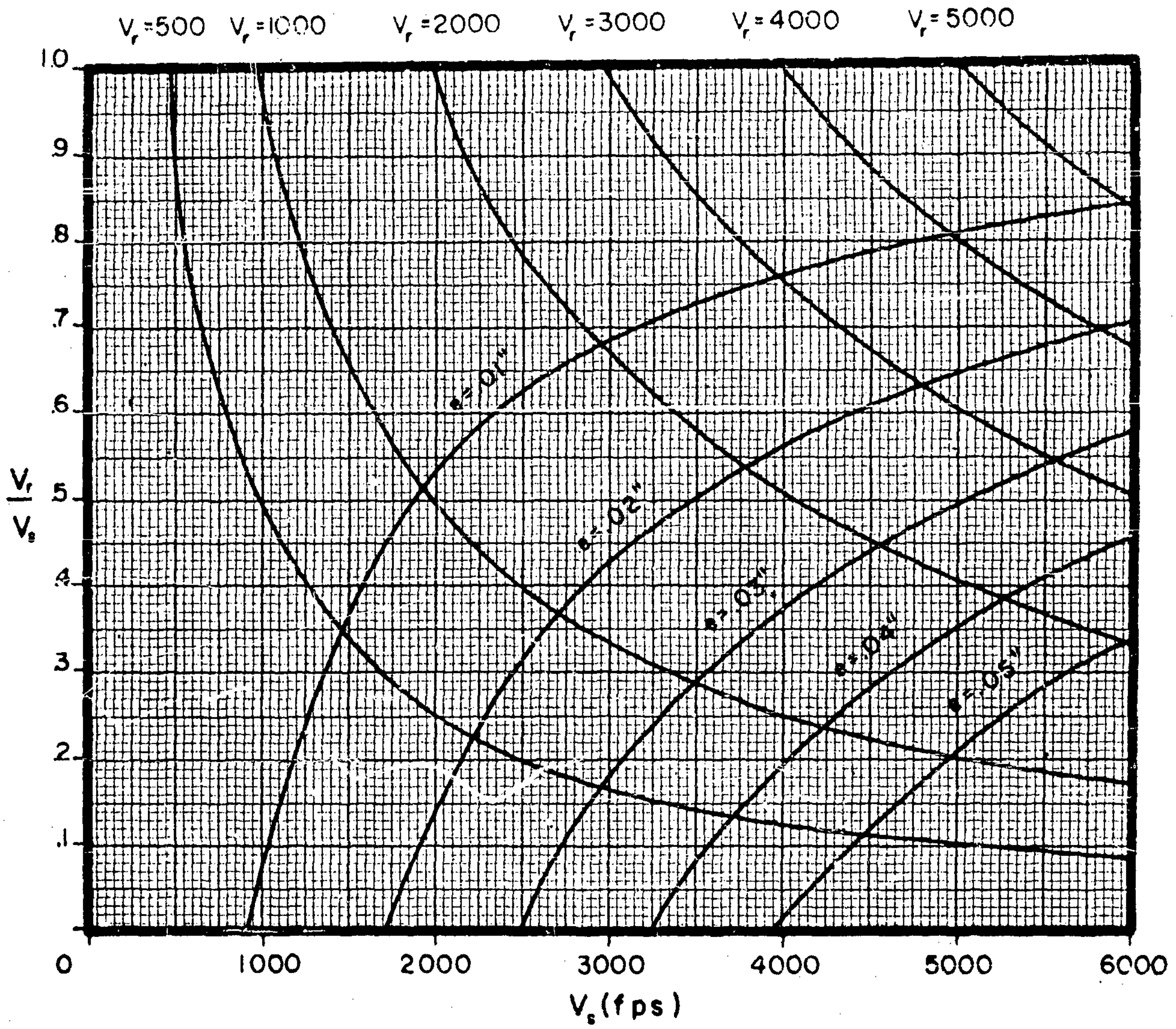
Fragment:
- Type: BRL Pre-formed
- Material: Steel
- Size: 30 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B=300)
Obliquity: 70°

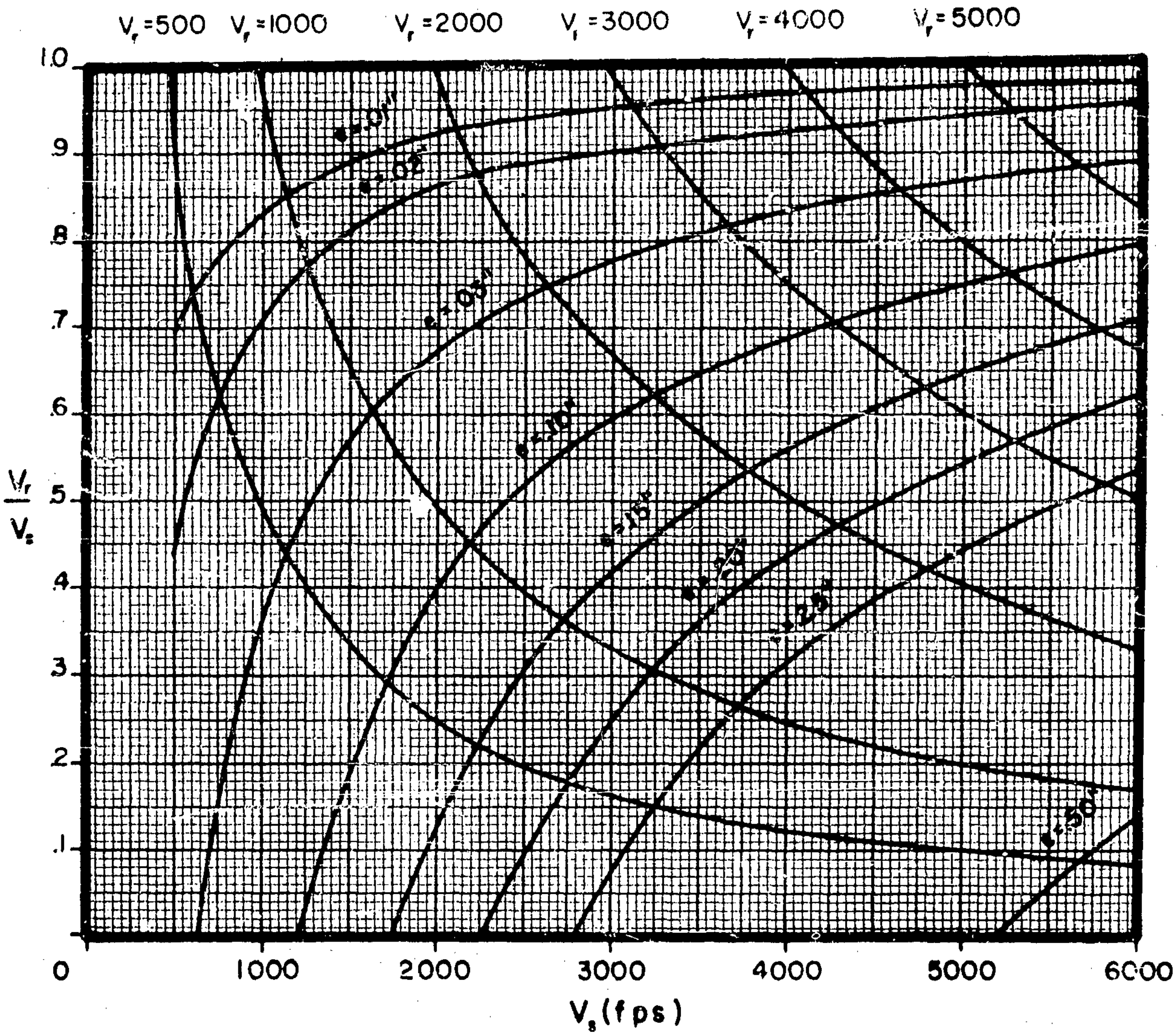
Fragment:
Type: BRL Pre-formed
Material: Steel
Size: 30 grains



Residual Velocity / Striking Velocity vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B=300)
Obliquity: 0°

Fragment:
Type: BRL Pre-formed
Material: Steel
Size: 100 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B=300)

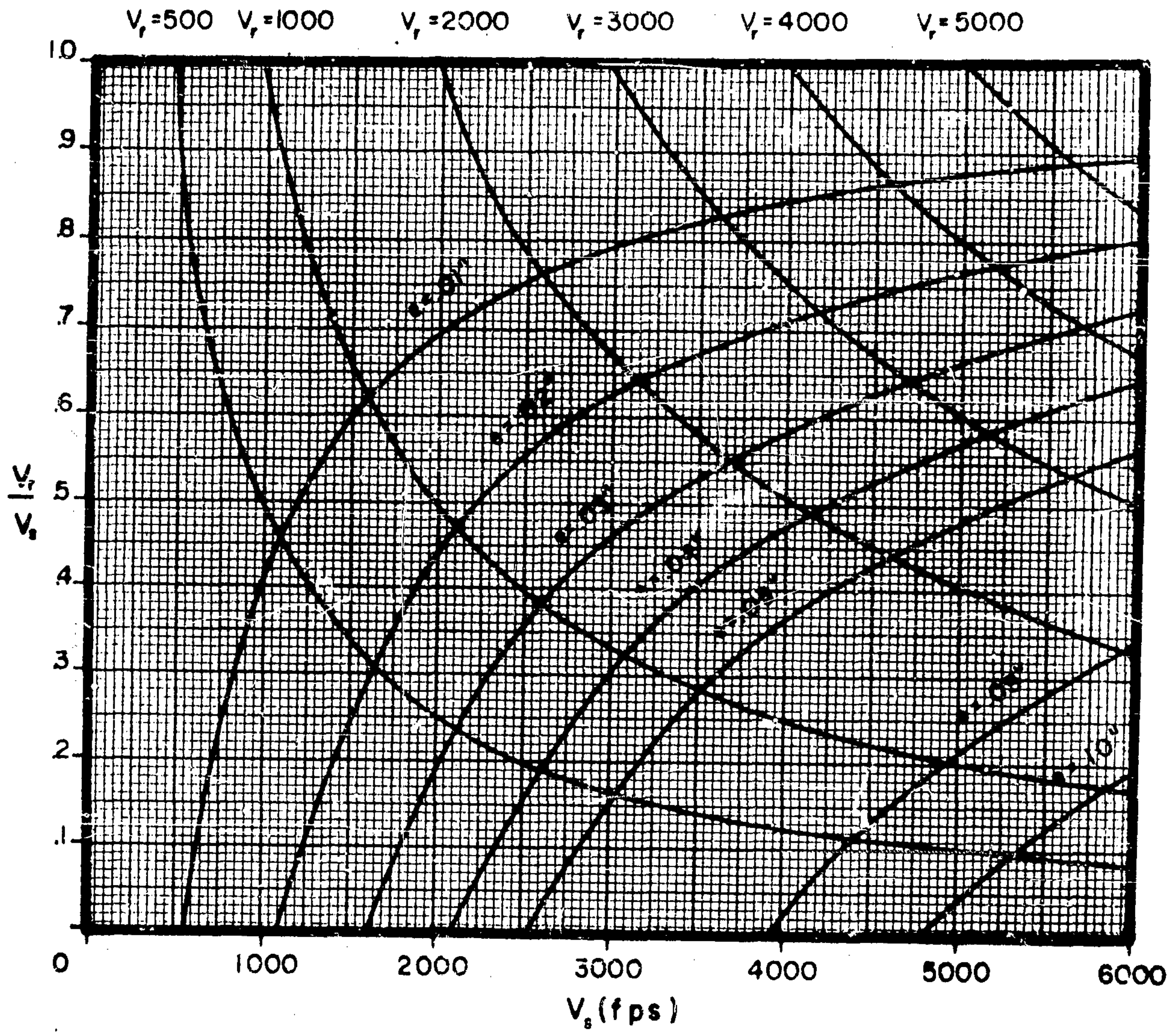
Obliquity: 70°

Fragment:

Type: BRL Pre-formed

Material: Steel

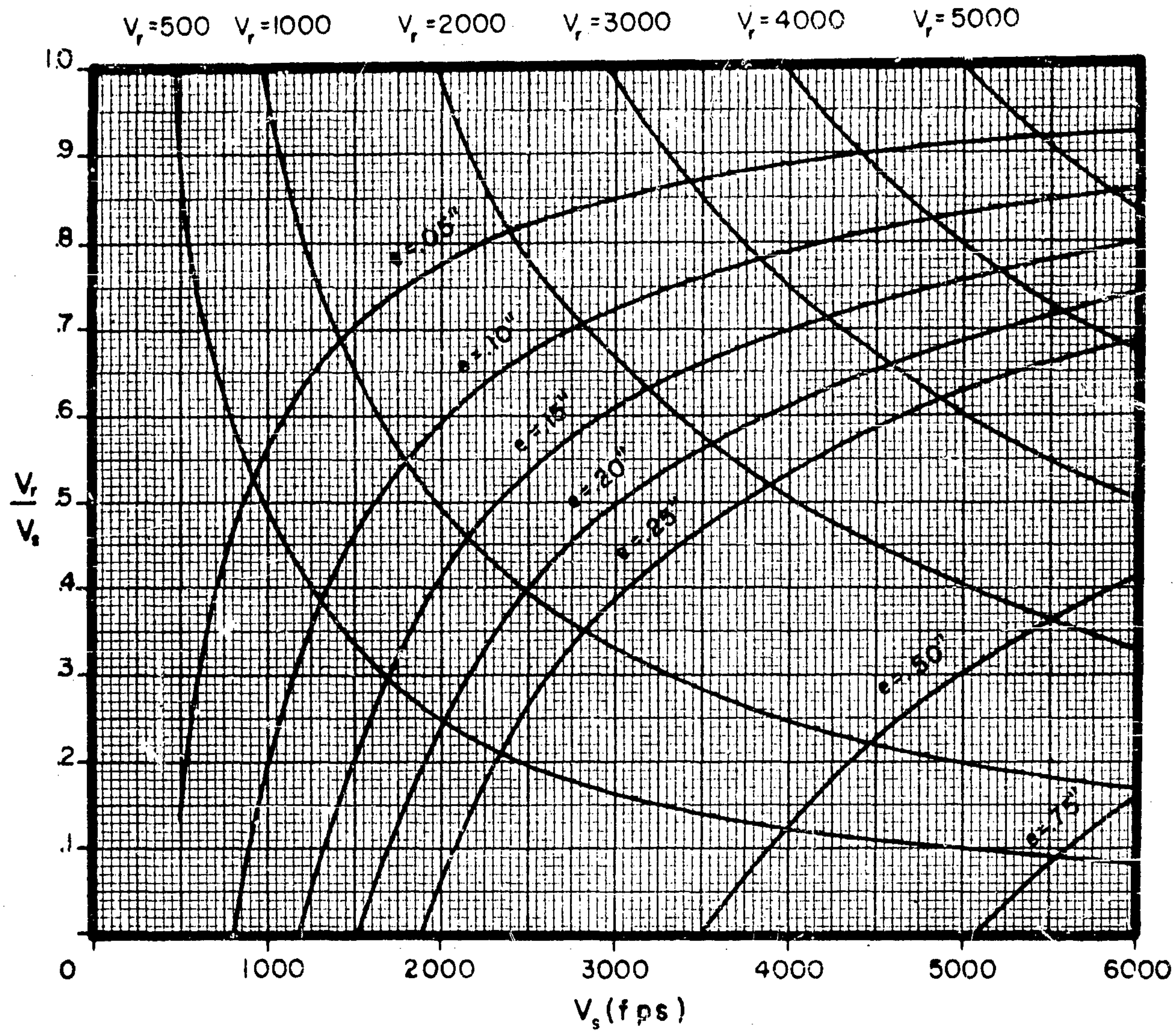
Size: 100 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B=300)
Obliquity: 0°

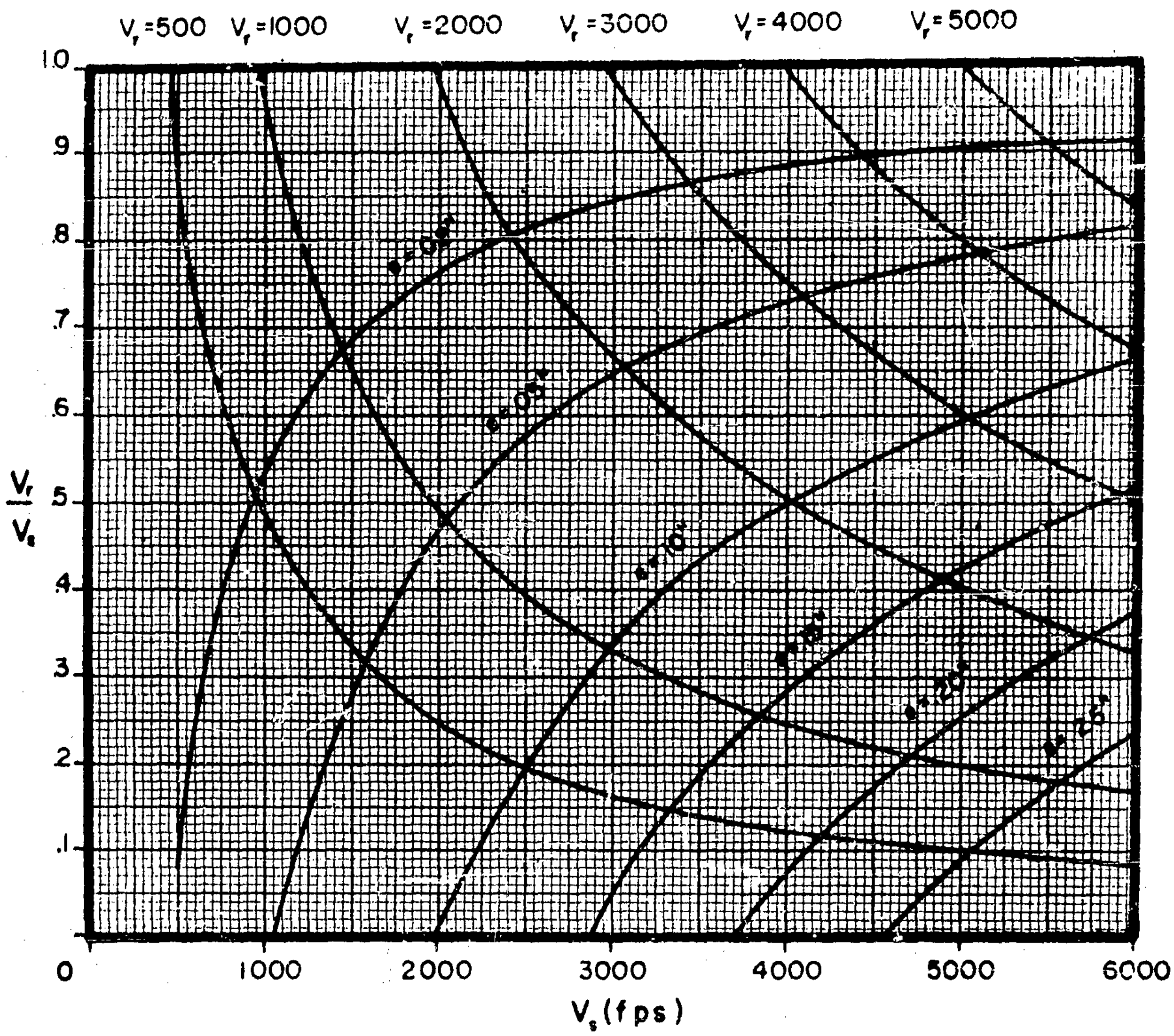
Fragment:
Type: BRL Pre-formed
Material: Steel
Size: 300 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B=300)
Obliquity: 60°

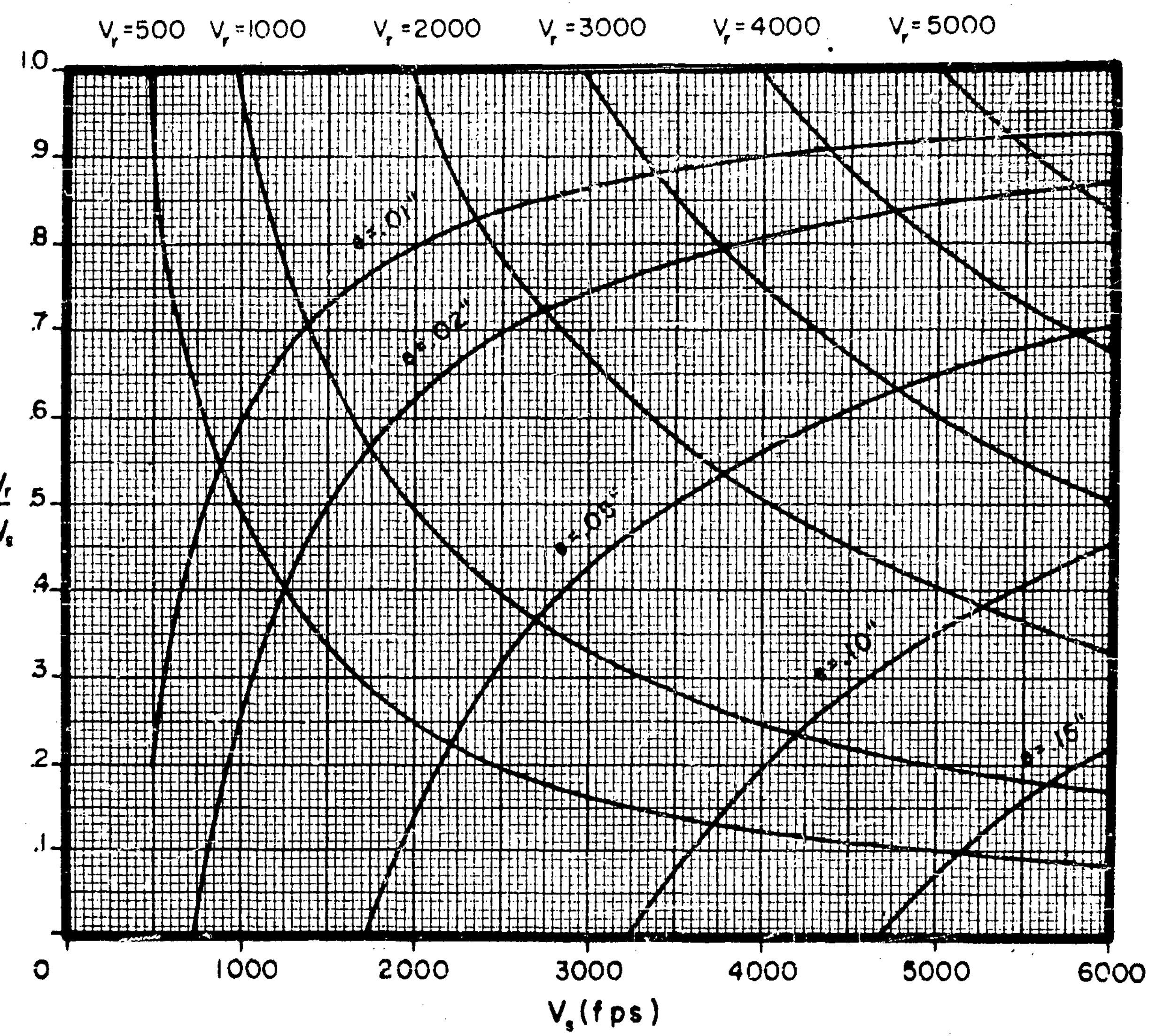
Fragment:
Type: BRL Pre-formed
Material: Steel
Size: 300 grains



$\frac{\text{Residual Velocity}}{\text{Striking Velocity}}$ vs Striking Velocity for Selected Plate Thicknesses

Plate Material: Steel (B=300)
Obliquity: 70°

Fragment:
Type: BRL Pre-formed
Material: Steel
Size: 300 grains



APPENDIX VII

Steel Fragments vs Steel Plate

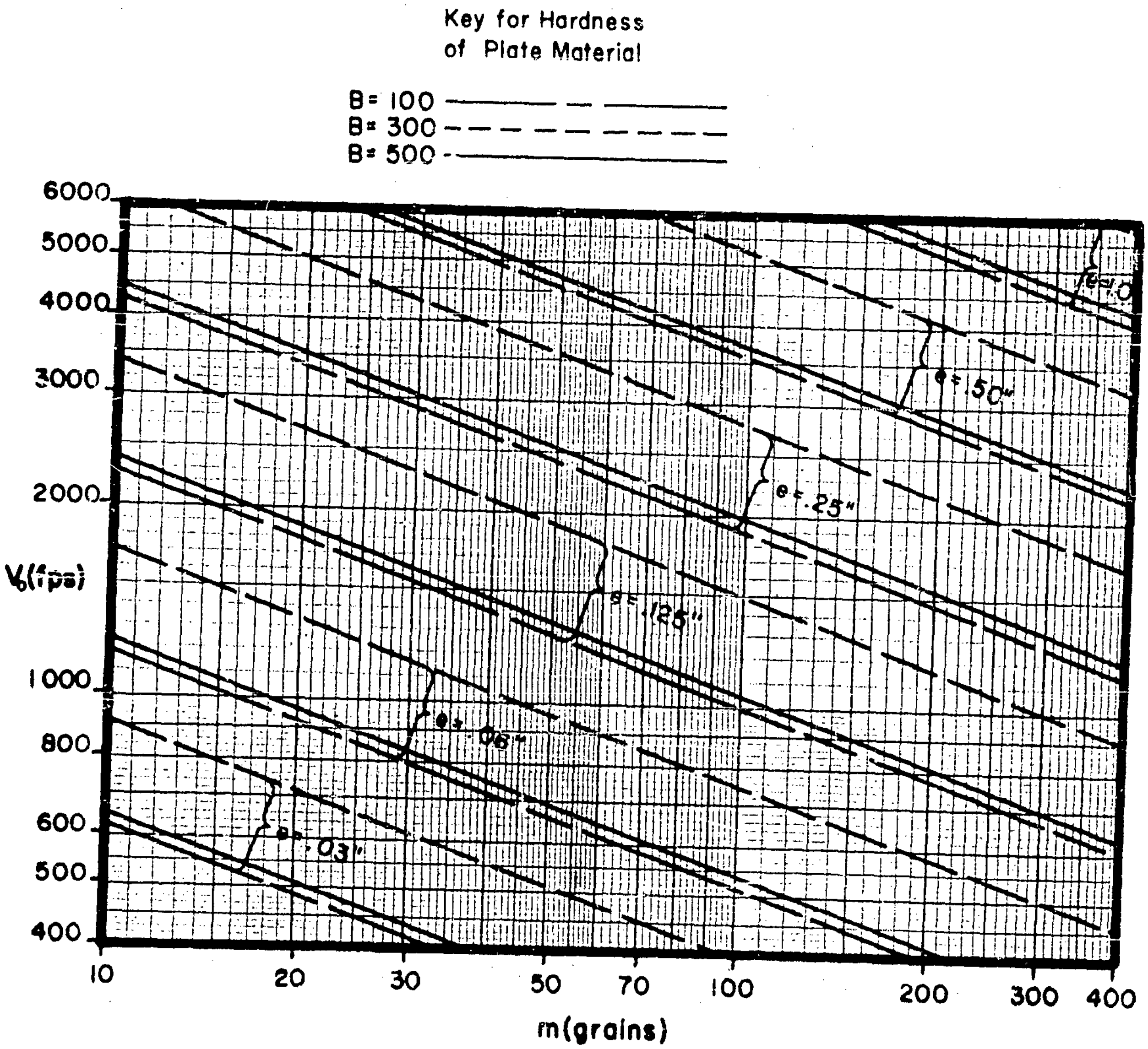
C. V_o vs Fragment Weight for Selected Plate Thicknesses;

B=100, 300, 500

V_o vs Fragment Weight for Selected Plate Thicknesses

Plate Material: Steel
Obliquity: 0°

Fragment:
Type. B R L Pre-formed
Material: Steel



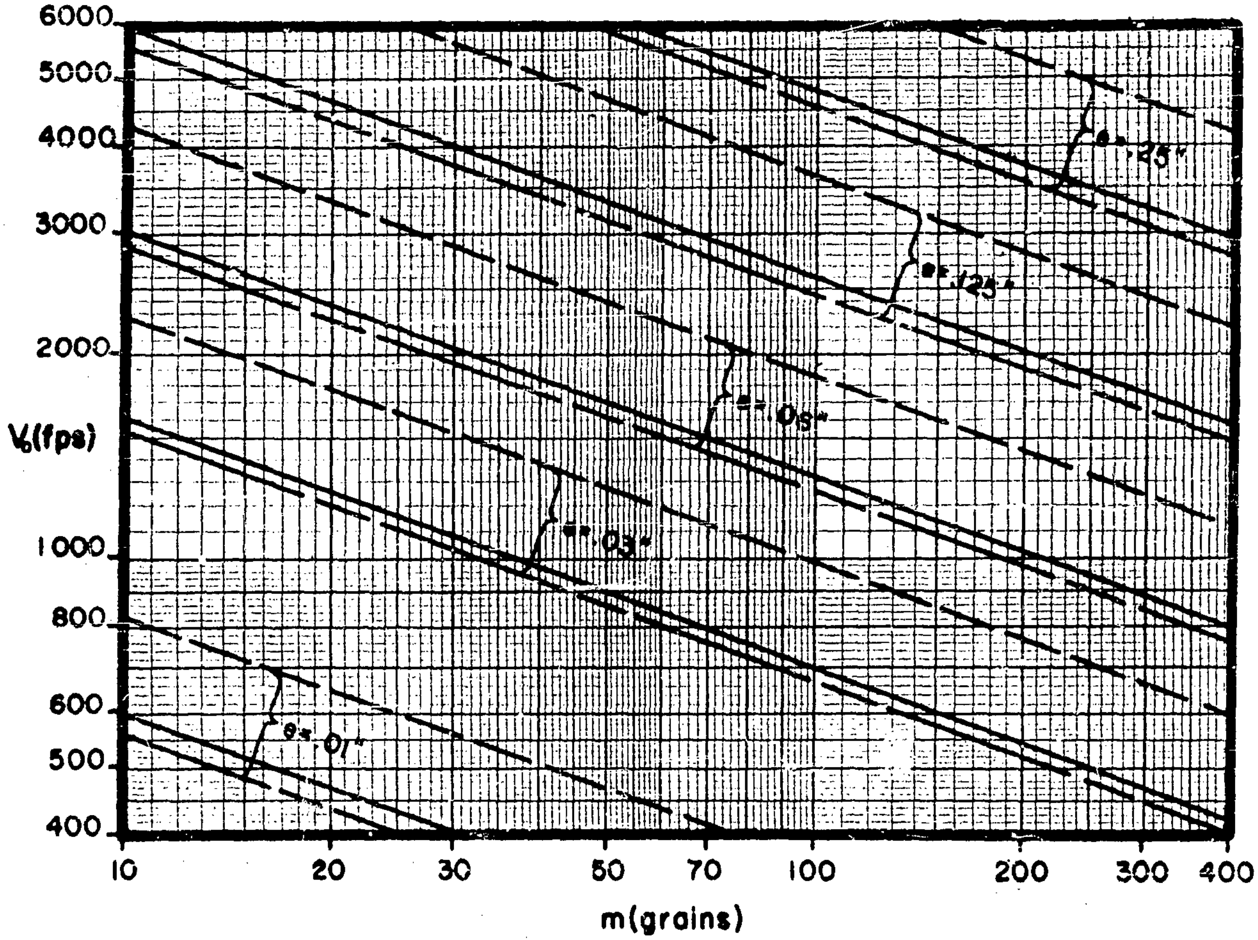
V₀ vs Fragment Weight for Selected Plate Thicknesses

Plate Material: Steel
Obliquity: 60°

Fragment:
Type: B R L Pre-formed
Material: Steel

Key for Hardness of Plate Material

B = 100
B = 300
B = 500



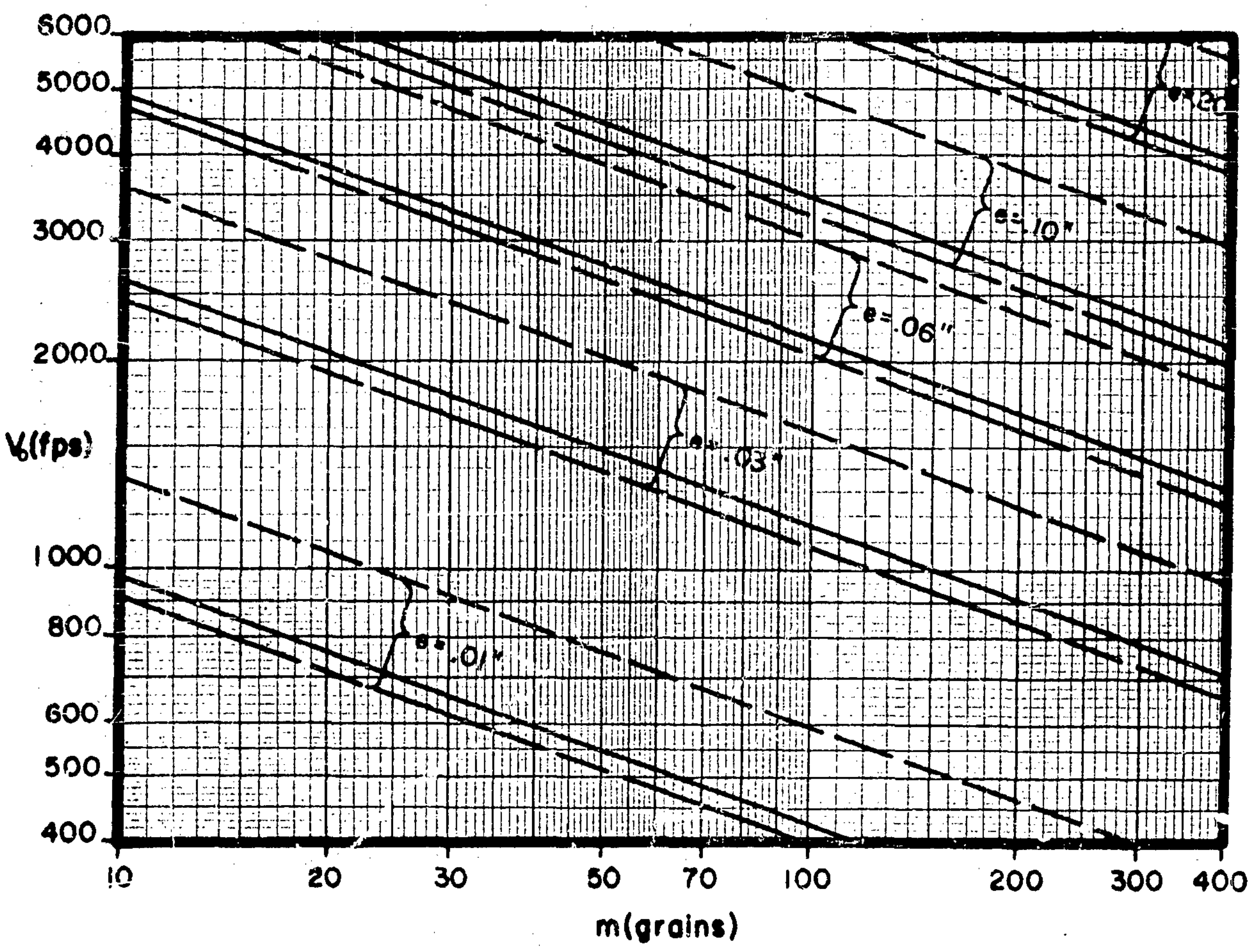
V₀ vs Fragment Weight for Selected Plate Thicknesses

Plate Material: Steel
Obliquity: 70°

Fragment:
Type: B R L Pre-formed
Material: Steel

Key for Hardness of Plate Material

B = 100
B = 300
B = 500



APPENDIX VIII

Comparison of the Performance of Steel and Tungsten Alloy Fragments

Impacting on Steel Plate

A. Residual Velocity vs Plate Thickness for Selected

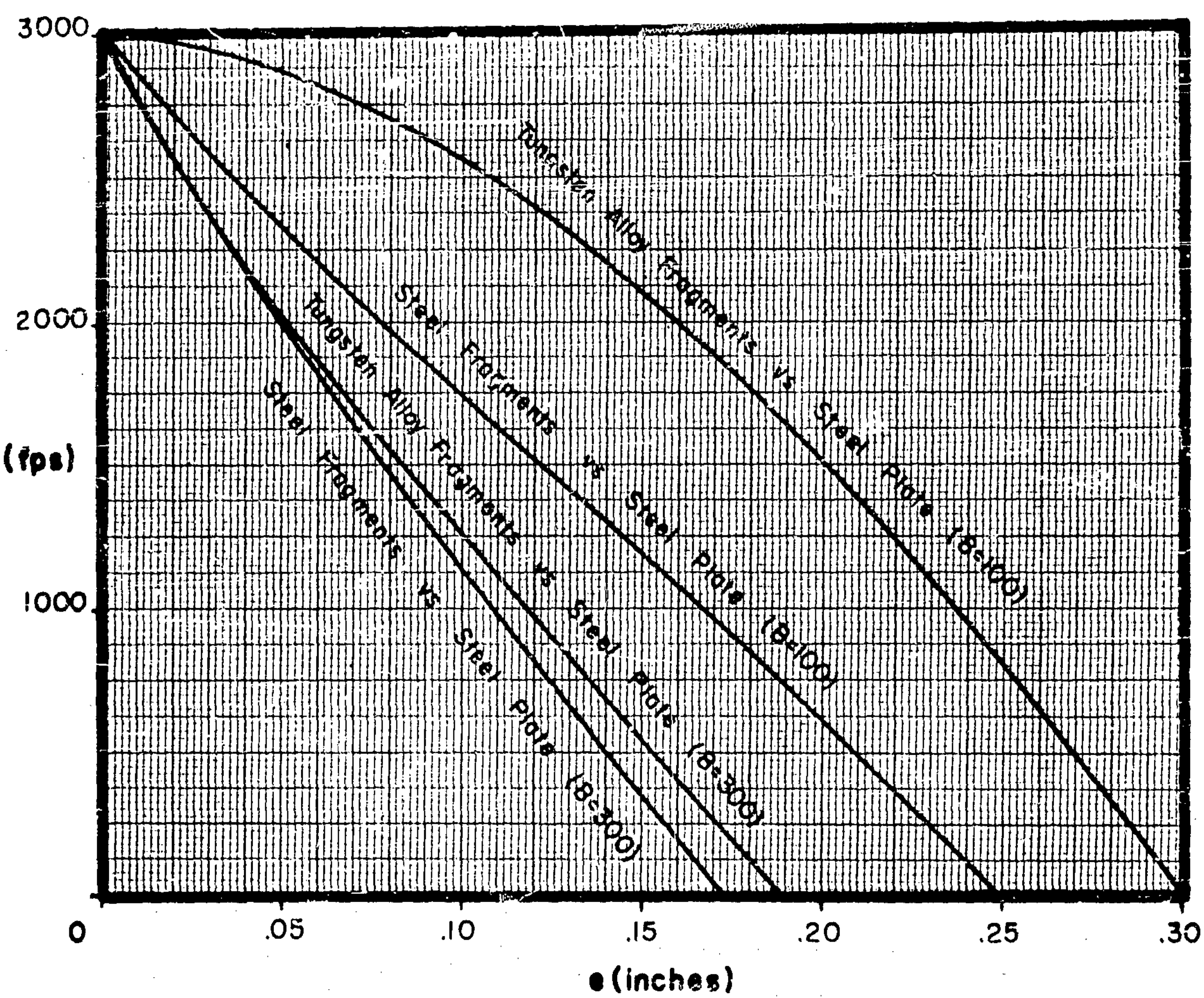
Combinations of Angle of Obliquity,

Fragment Weight, and Striking Velocity

Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Steel
Obliquity: 0°
Striking Velocity: 3000 fps

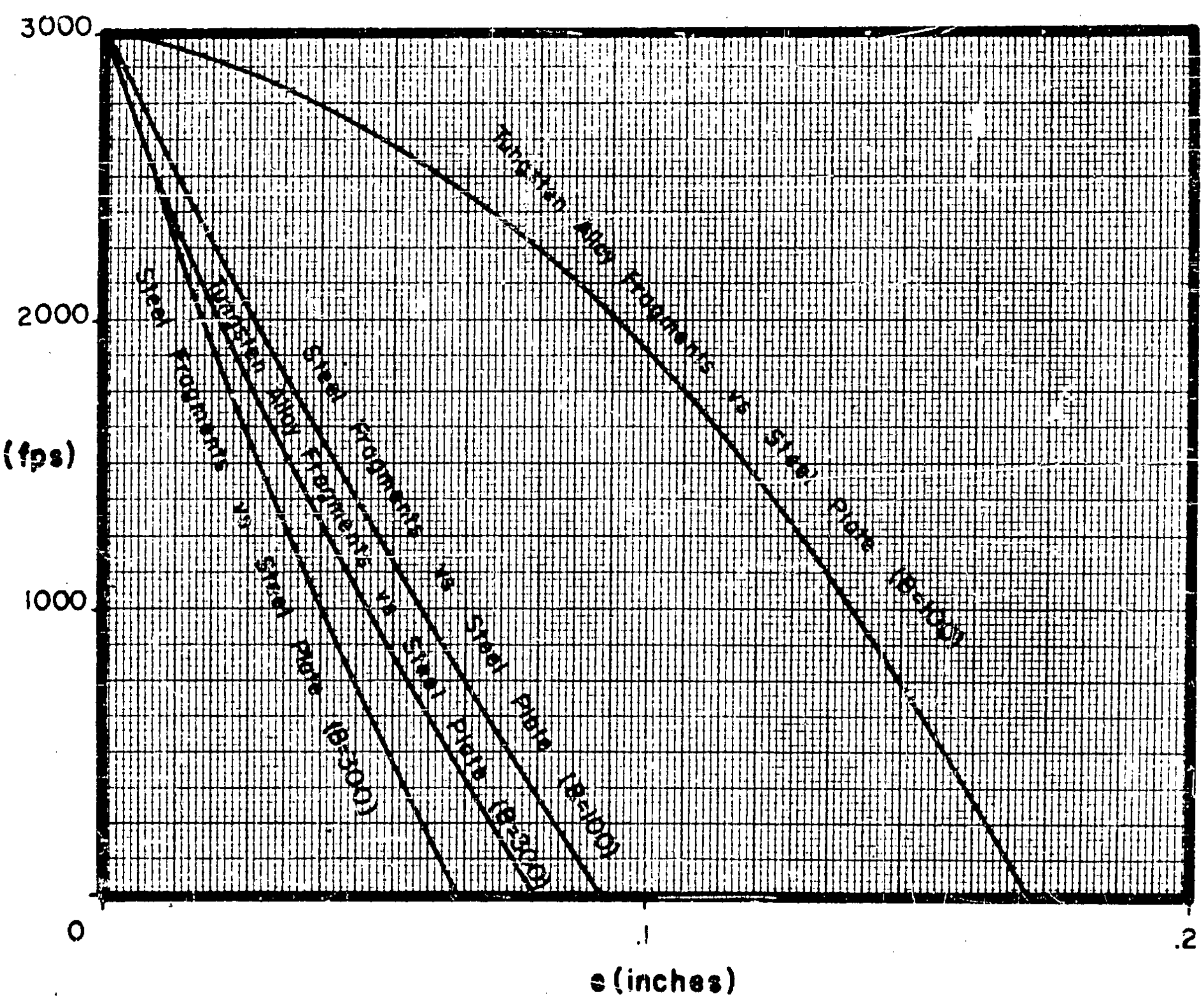
Fragment:
Type: BRL Pre-formed
Size: 30 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Steel
Obliquity: 60°
Striking Velocity: 3000 fps

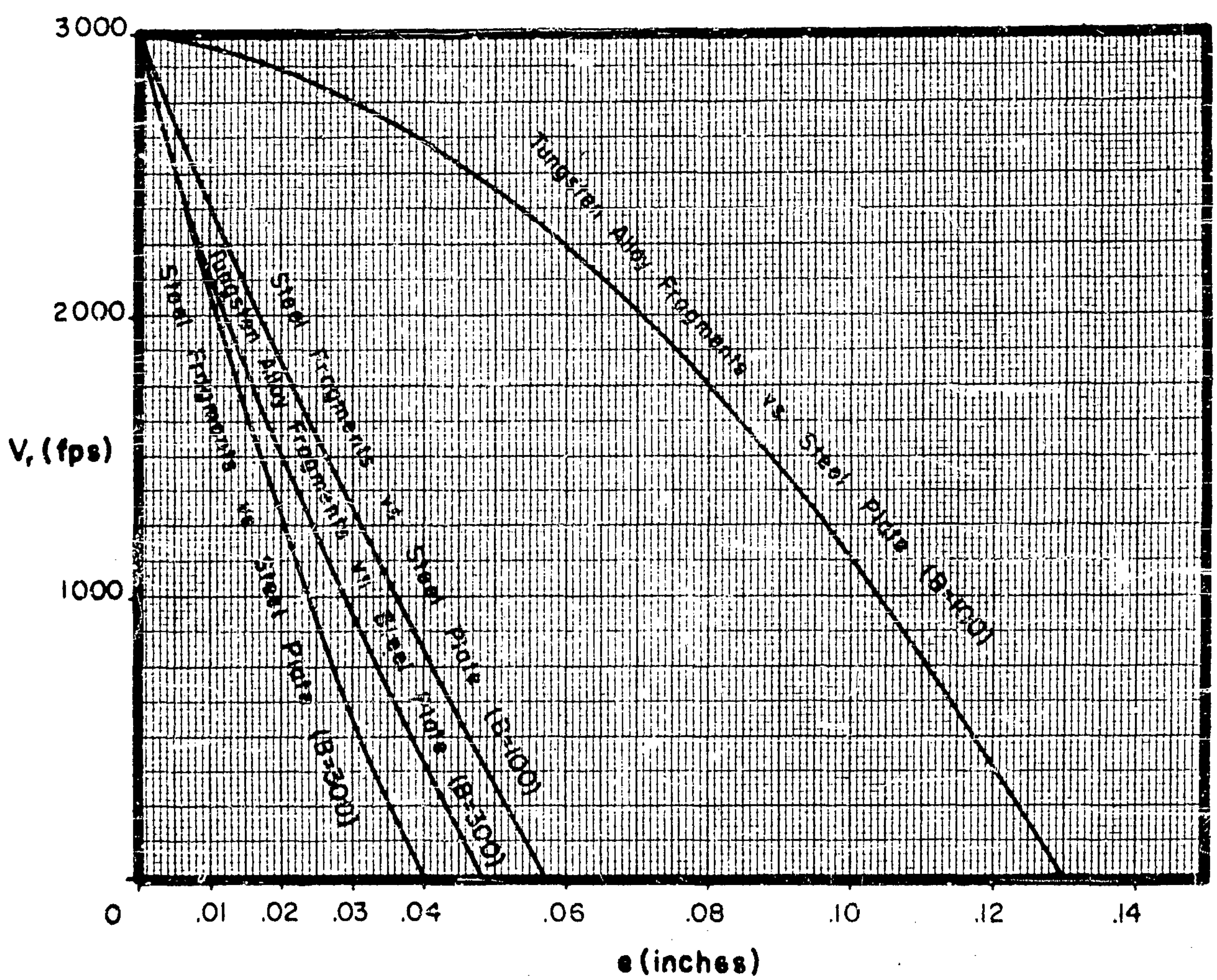
Fragment:
Type: BRL Pre-formed
Size: 30 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Steel
Obliquity: 70°
Striking Velocity: 3000 fps

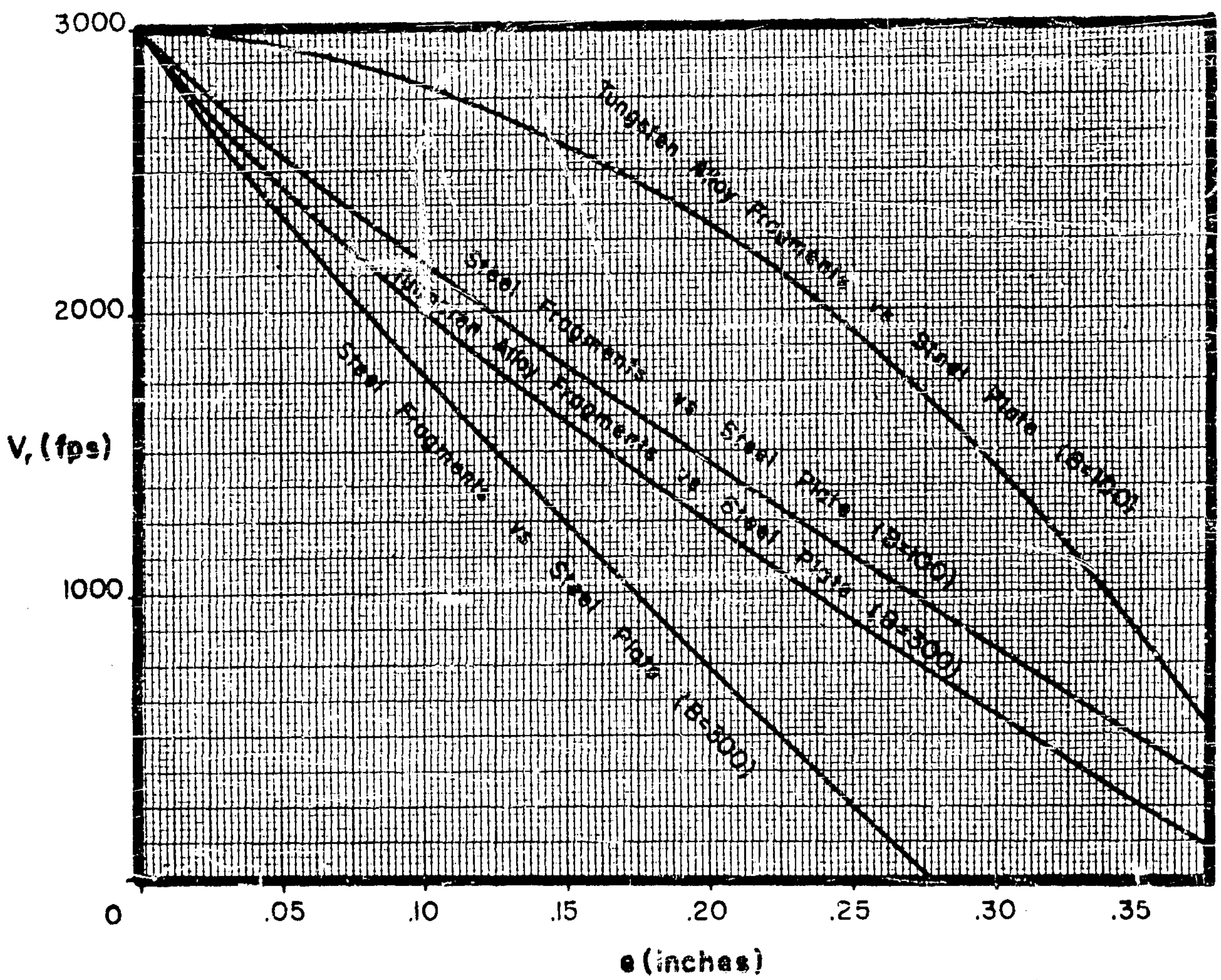
Fragment:
Type: BRL Pre-formed
Size: 30 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Steel
Obliquity: 0°
Striking Velocity: 3000 fps

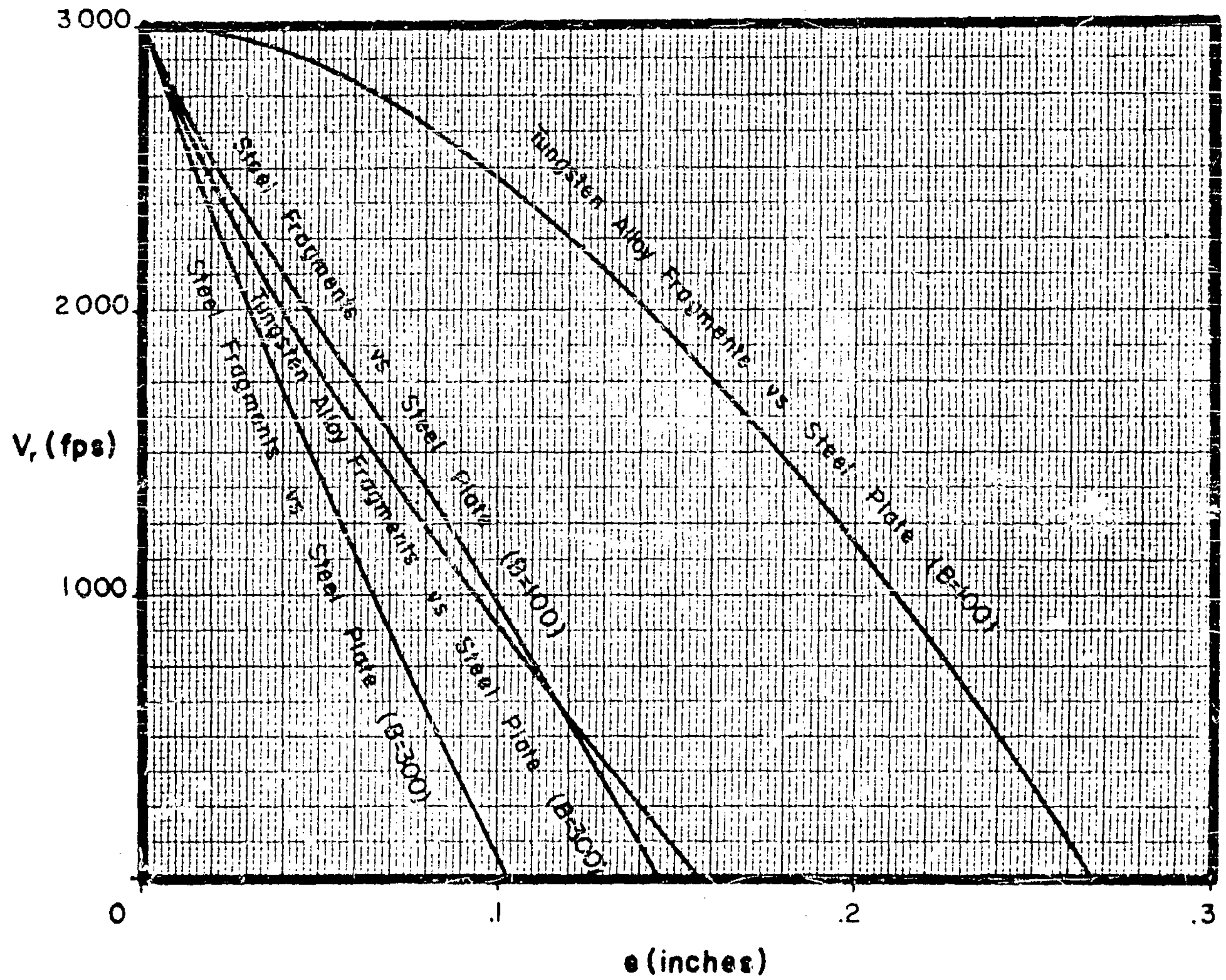
Fragment:
Type: BRL Pre-formed
Size: 100 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Steel
Obliquity: 60°
Striking Velocity: 3000 fps

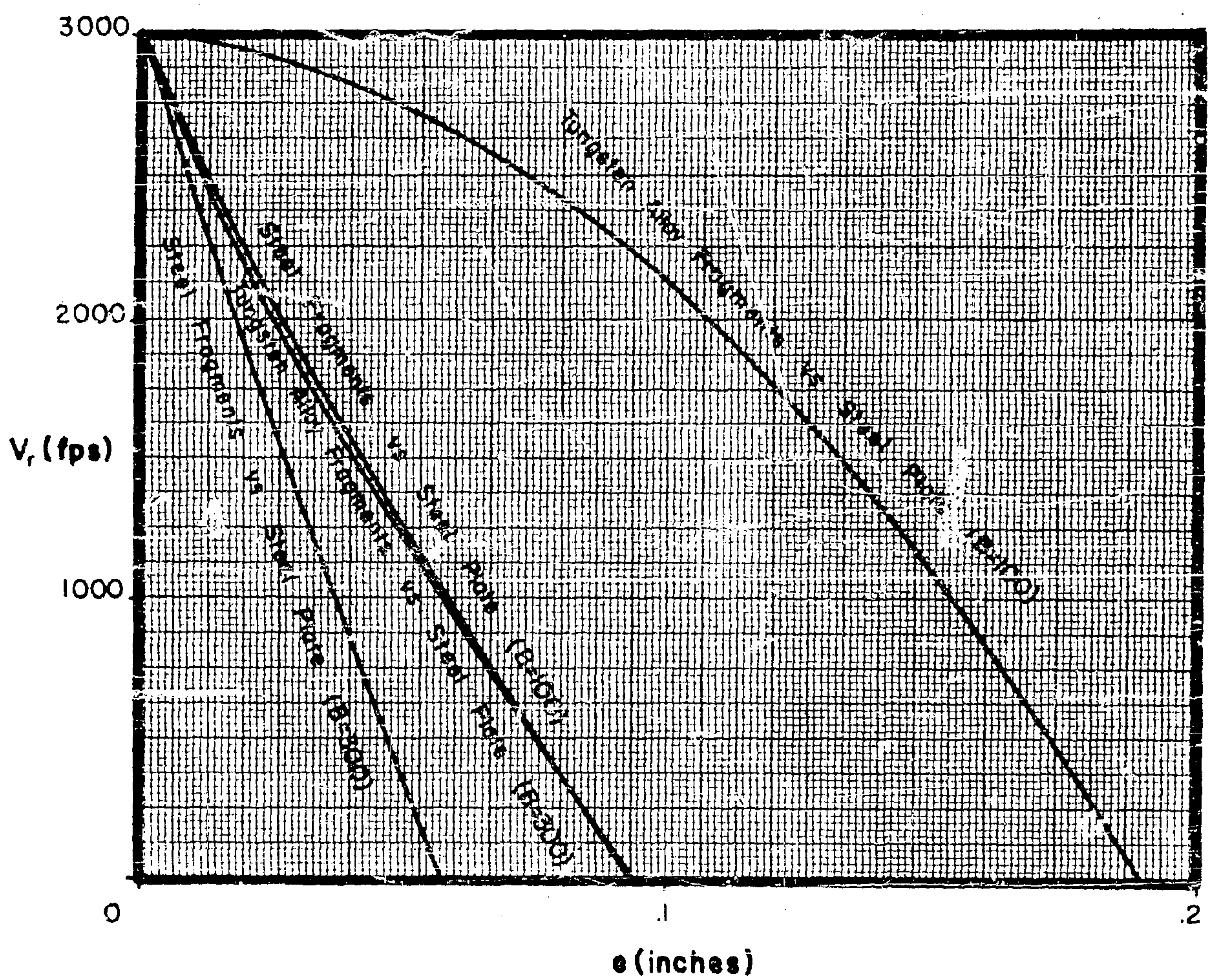
Fragment:
Type: BRL Pre-formed
Size: 100 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Steel
Obliquity: 70°
Striking Velocity: 3000 fps

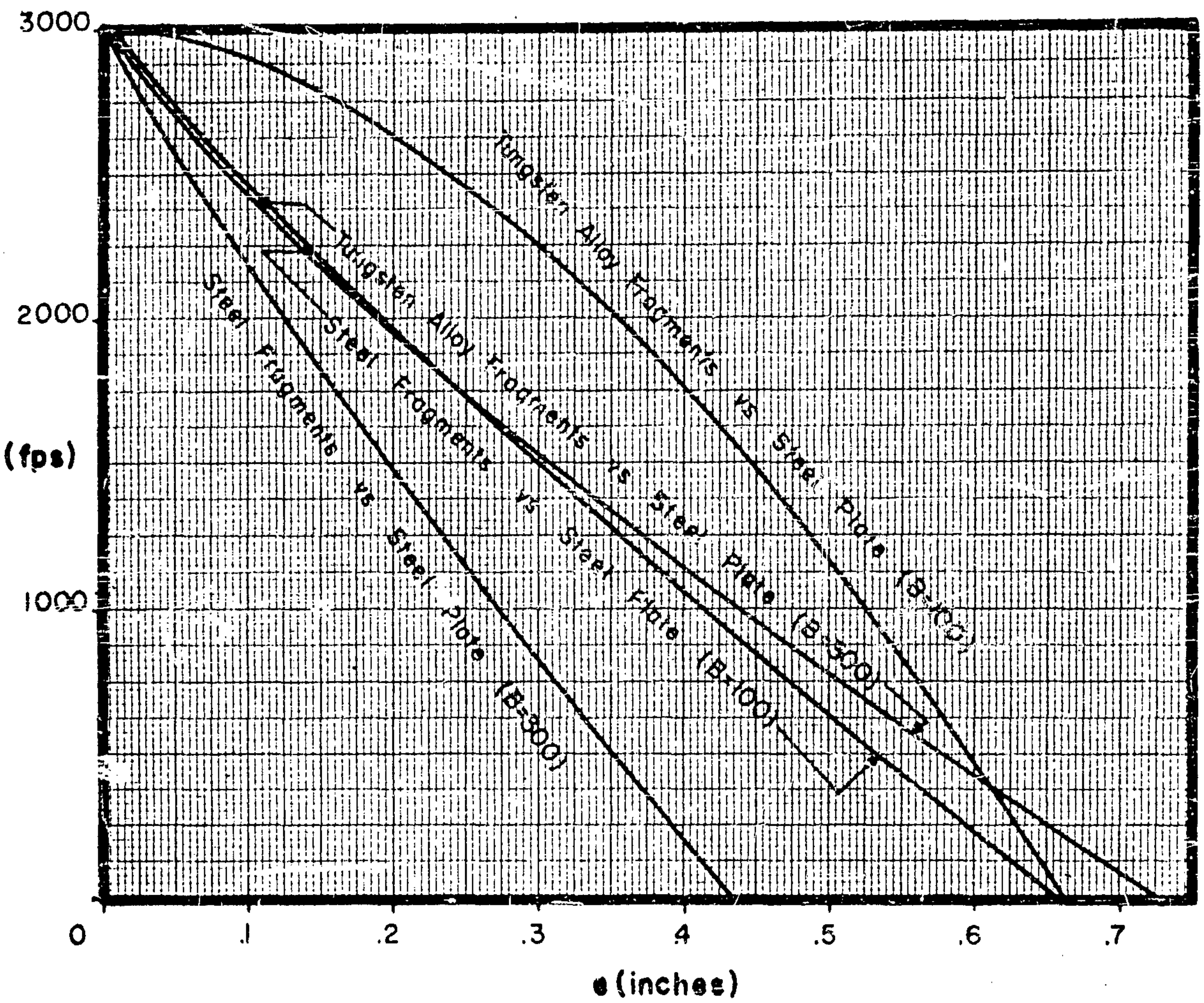
Fragment:
Type: B.R.L. Pre-formed
Size: 100 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Steel
Obliquity: 0°
Striking Velocity: 3000 fps

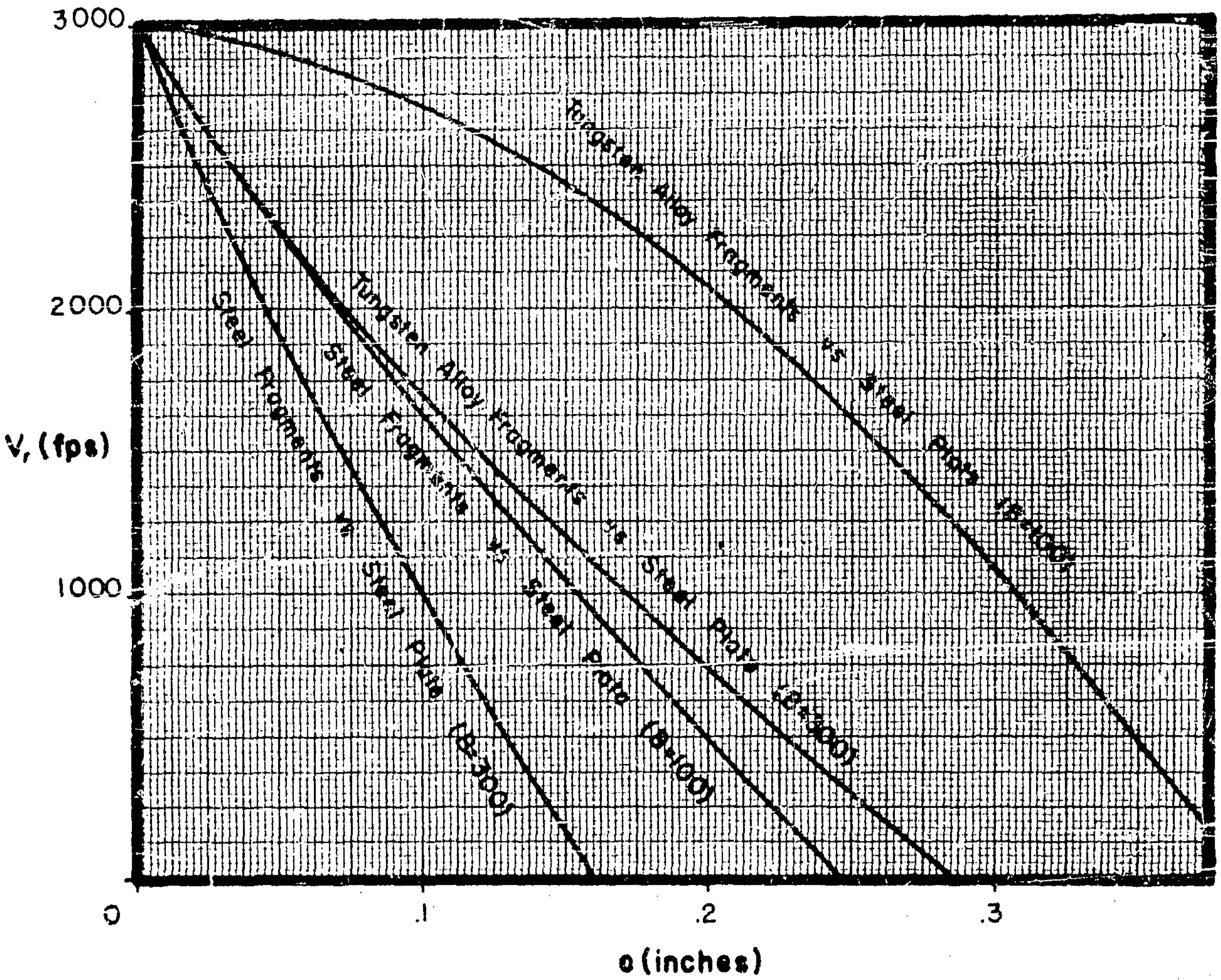
Fragment:
Type: BRL Pre-formed
Size: 300 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Steel
Obliquity: 60°
Striking Velocity: 3000 fps

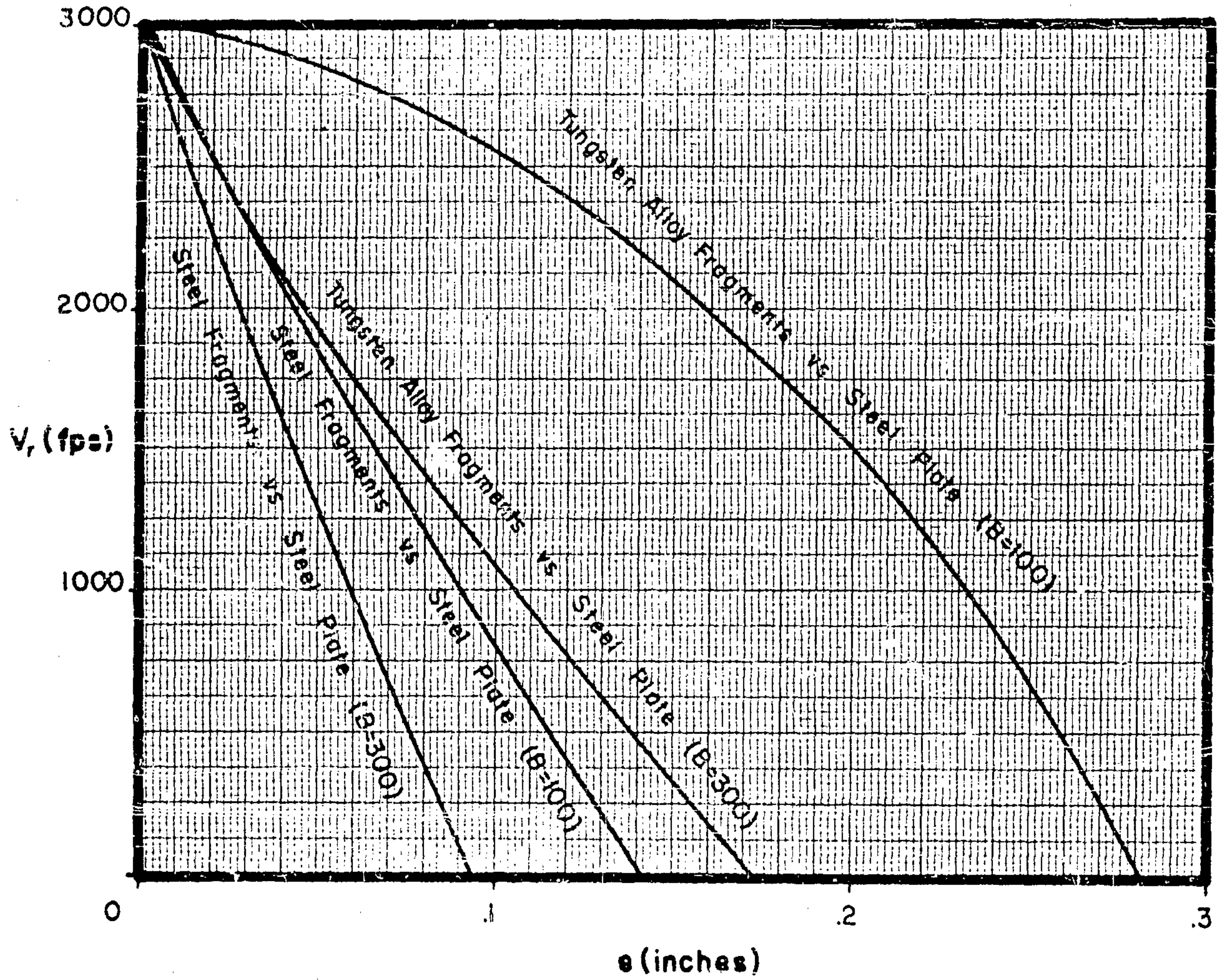
Fragment:
Type: BRL Pre-formed
Size: 300 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Steel
Obliquity: 70°
Striking Velocity: 3000 fps

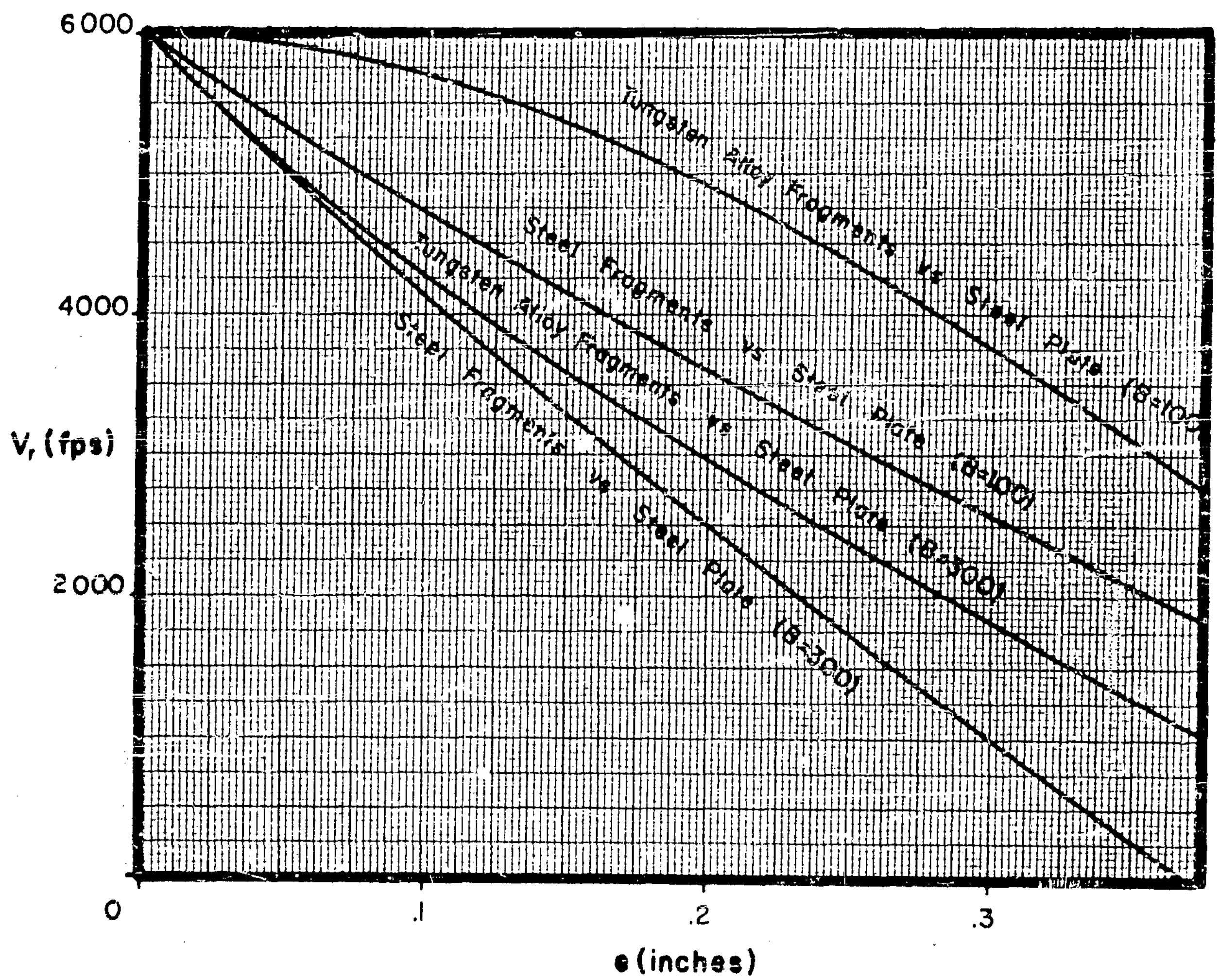
Fragment:
Type: BRL Pre-formed
Size: 300 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Steel
Obliquity: 0°
Striking Velocity: 6000 fps

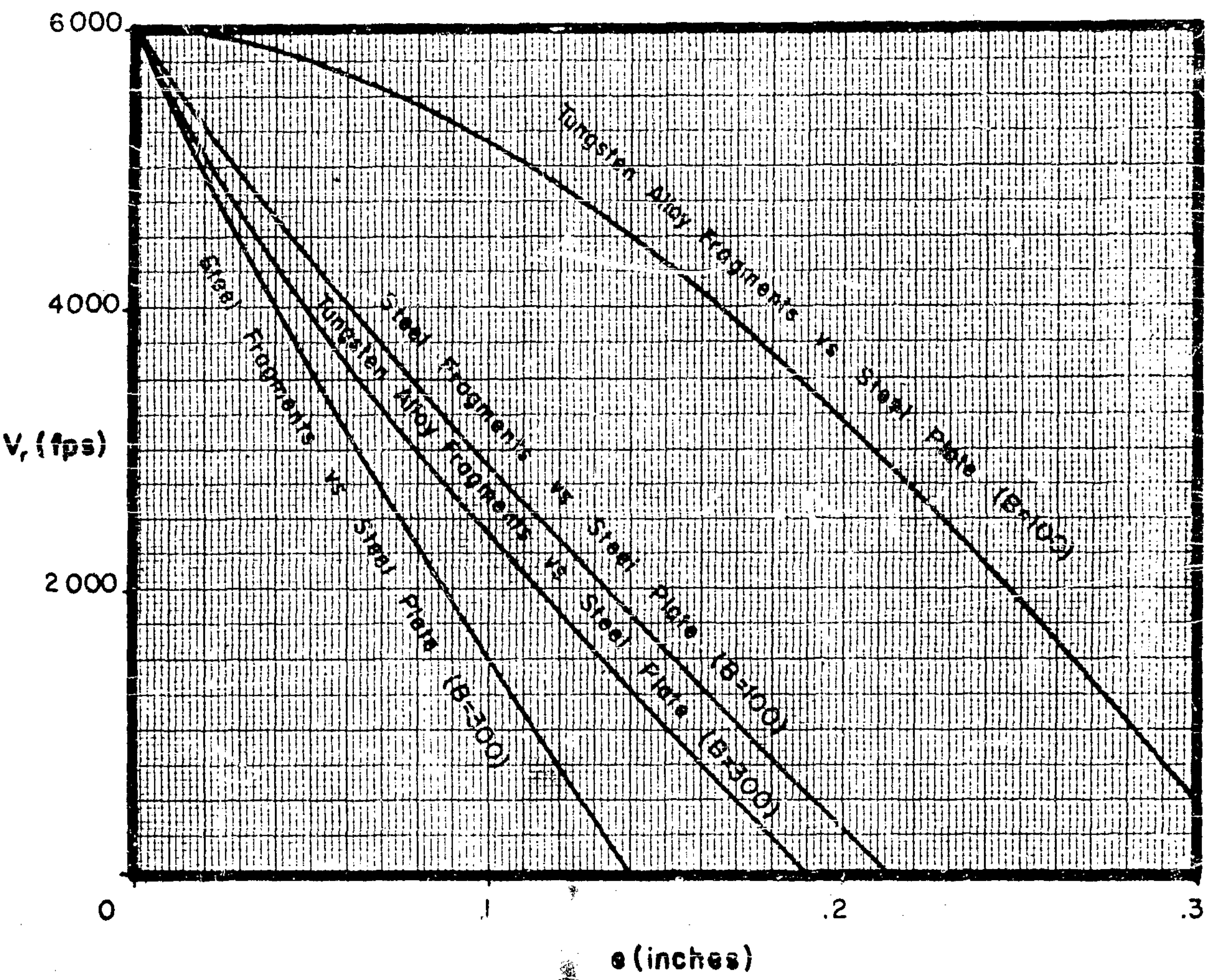
Fragment:
Type: BRL Pre-formed
Size: 30 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Steel
Obliquity: 60°
Striking Velocity: 6000 fps

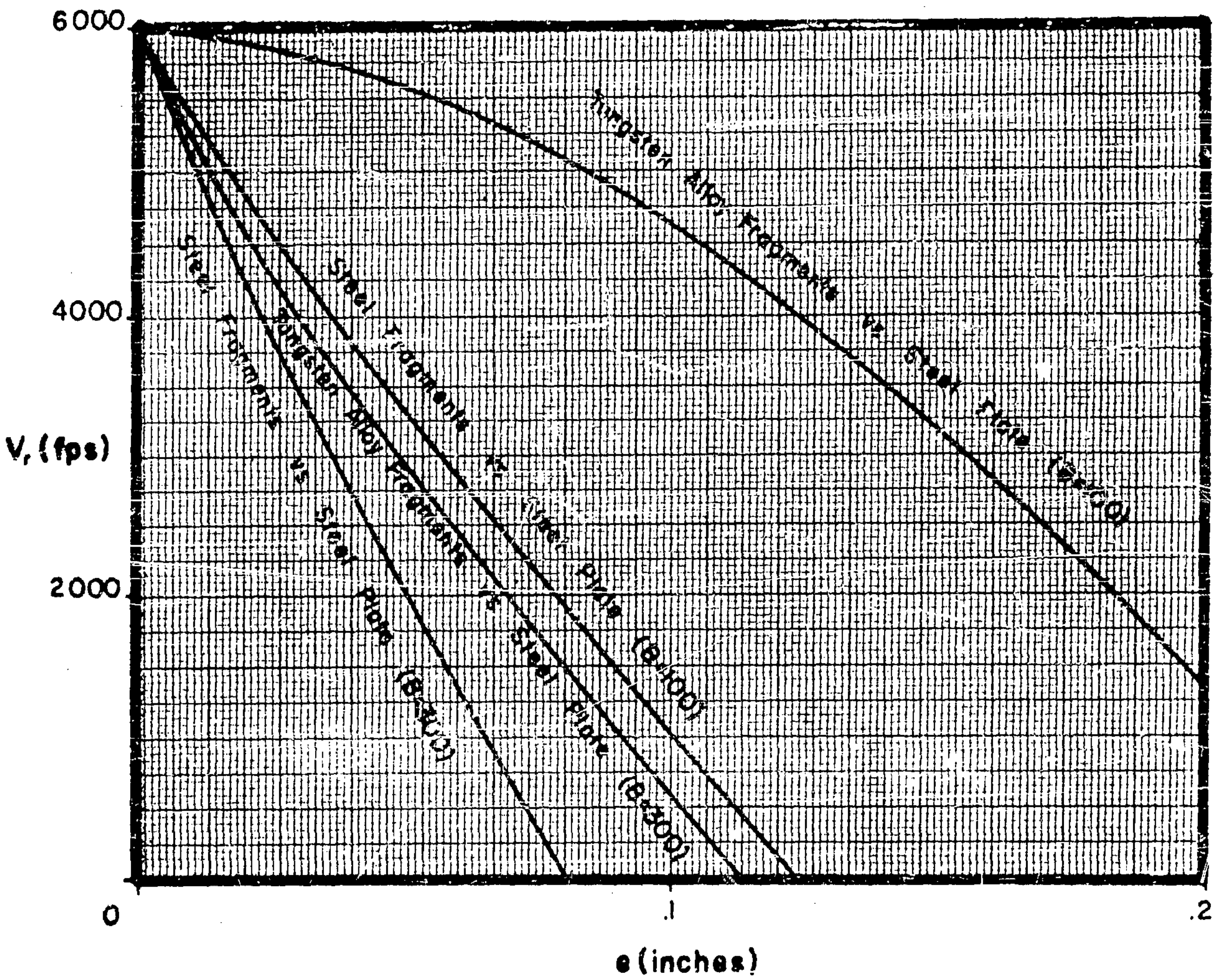
Fragment:
Type: BRL Pre-formed
Size: 30 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Steel
Obliquity: 70°
Striking Velocity: 6000 fps

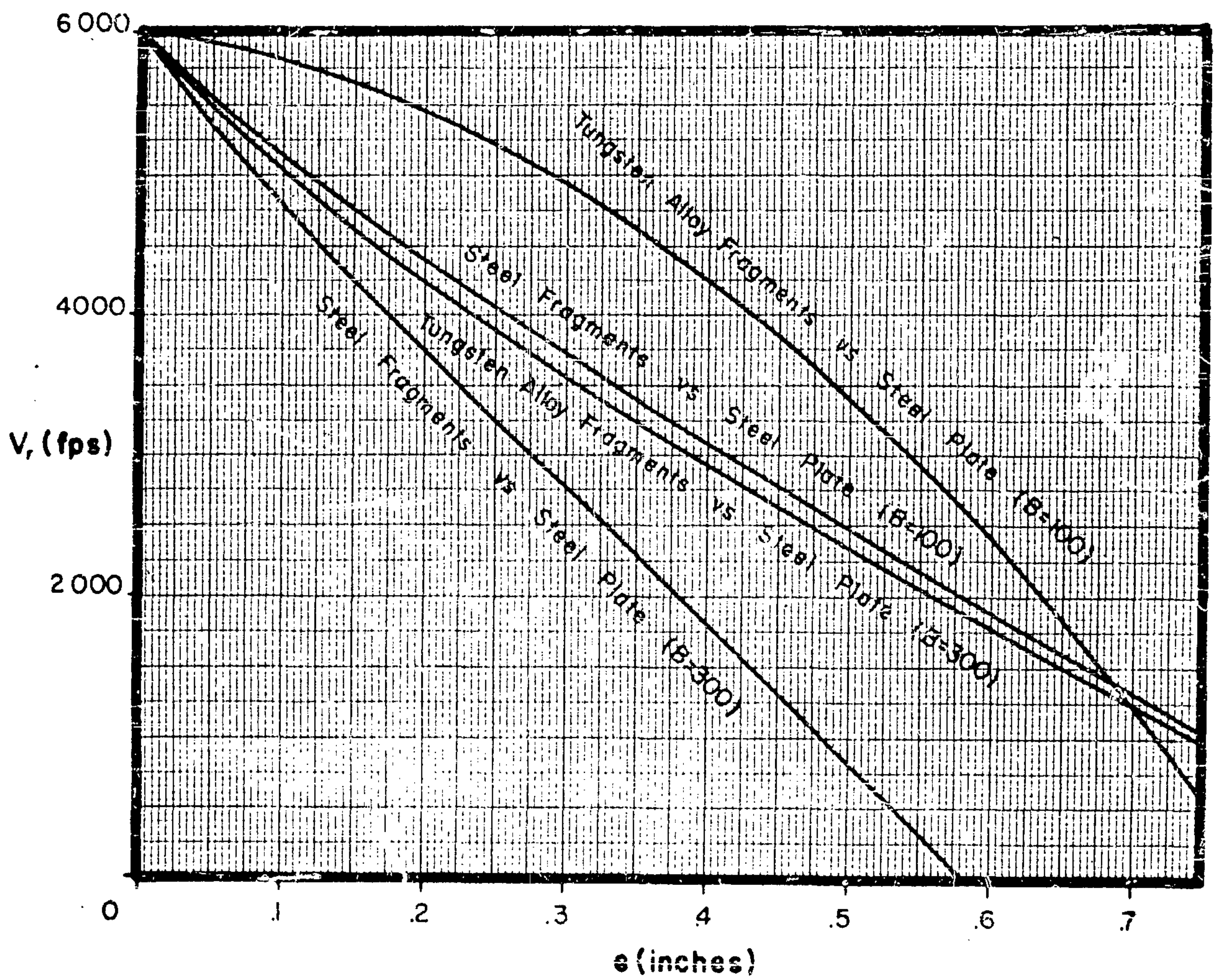
Fragment:
Type: BRL Pre-formed
Size: 30 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Steel
Obliquity: 0°
Striking Velocity: 6000 fps

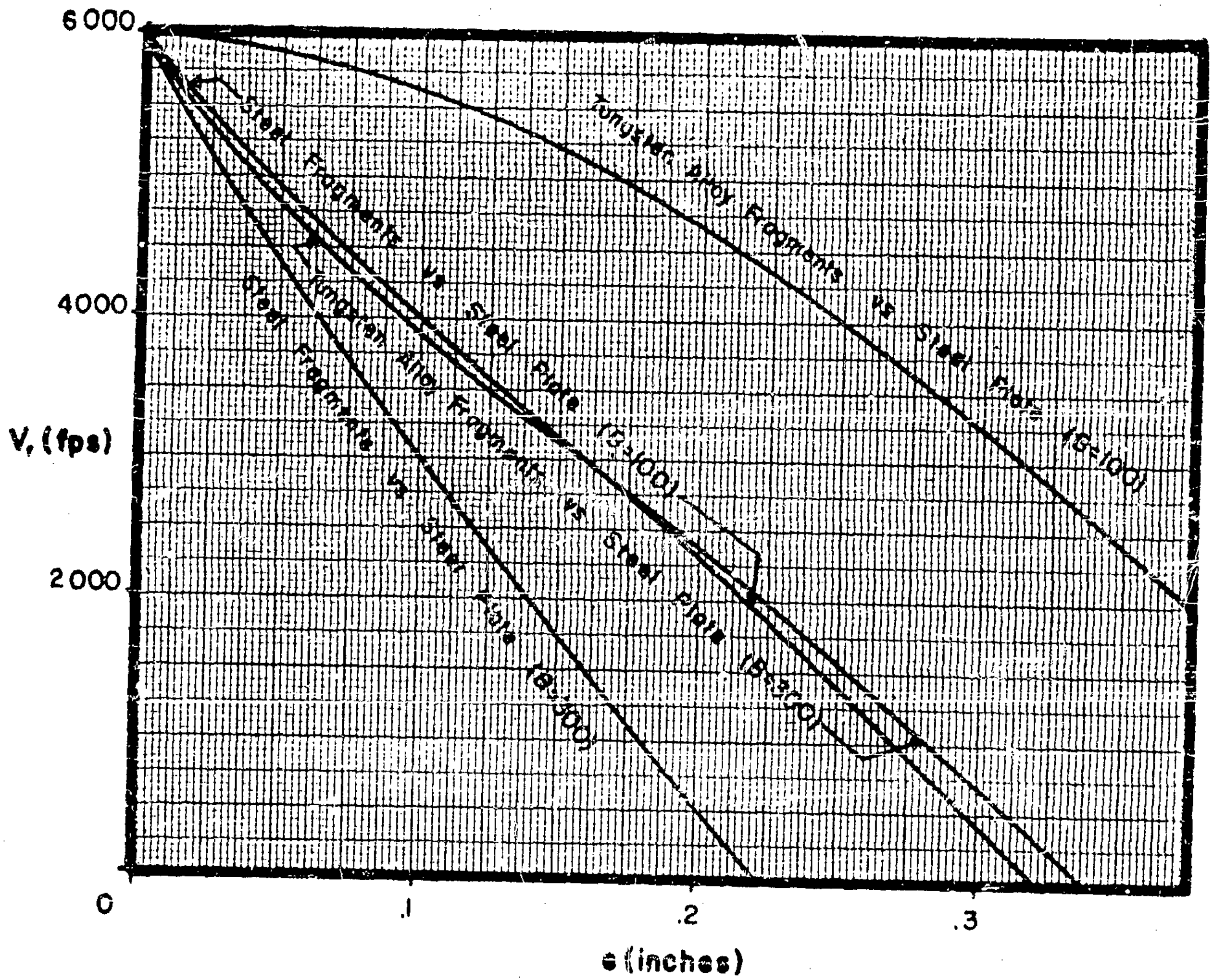
Fragment:
Type: BRL Pre-formed
Size: 100 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Steel
Obliquity: 60°
Striking Velocity: 6000 fps

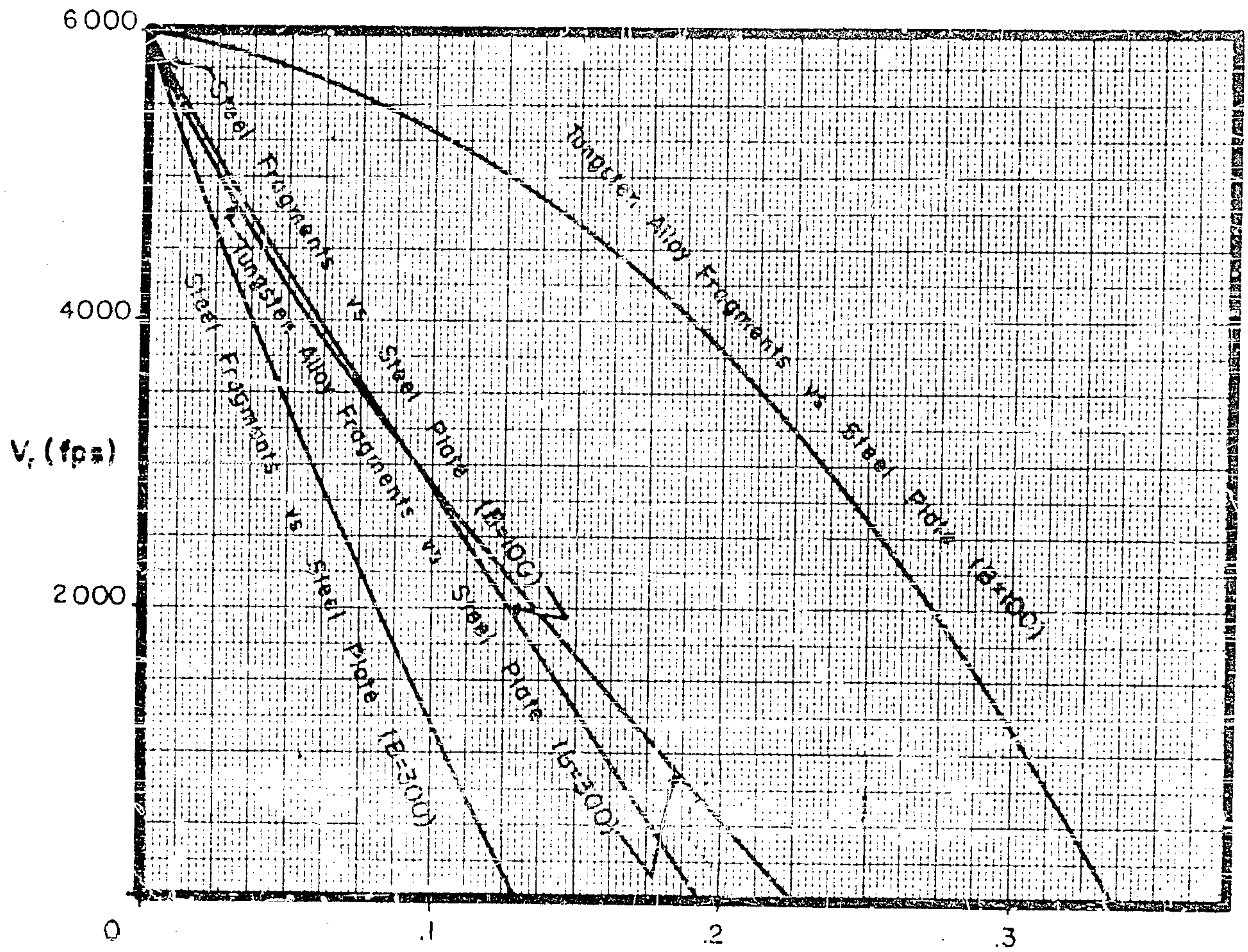
Fragment:
Type: BRL Pre-formed
Size: 100 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Steel
Obliquity: 70°
Striking Velocity: 6000 fps

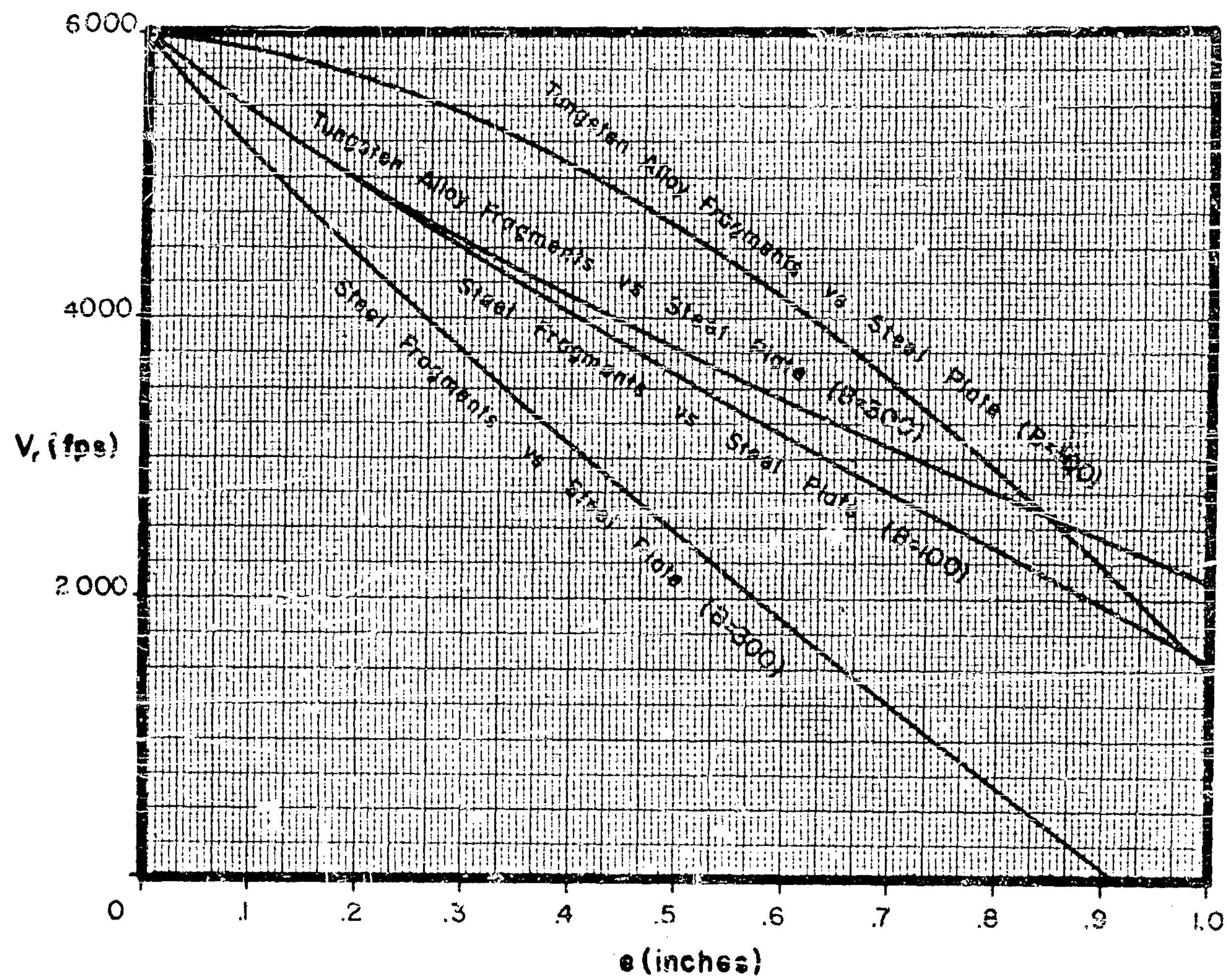
Fragment:
Type: BRL Pre-formed
Size: 100 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Steel
Obliquity: 0°
Striking Velocity: 6000 fps

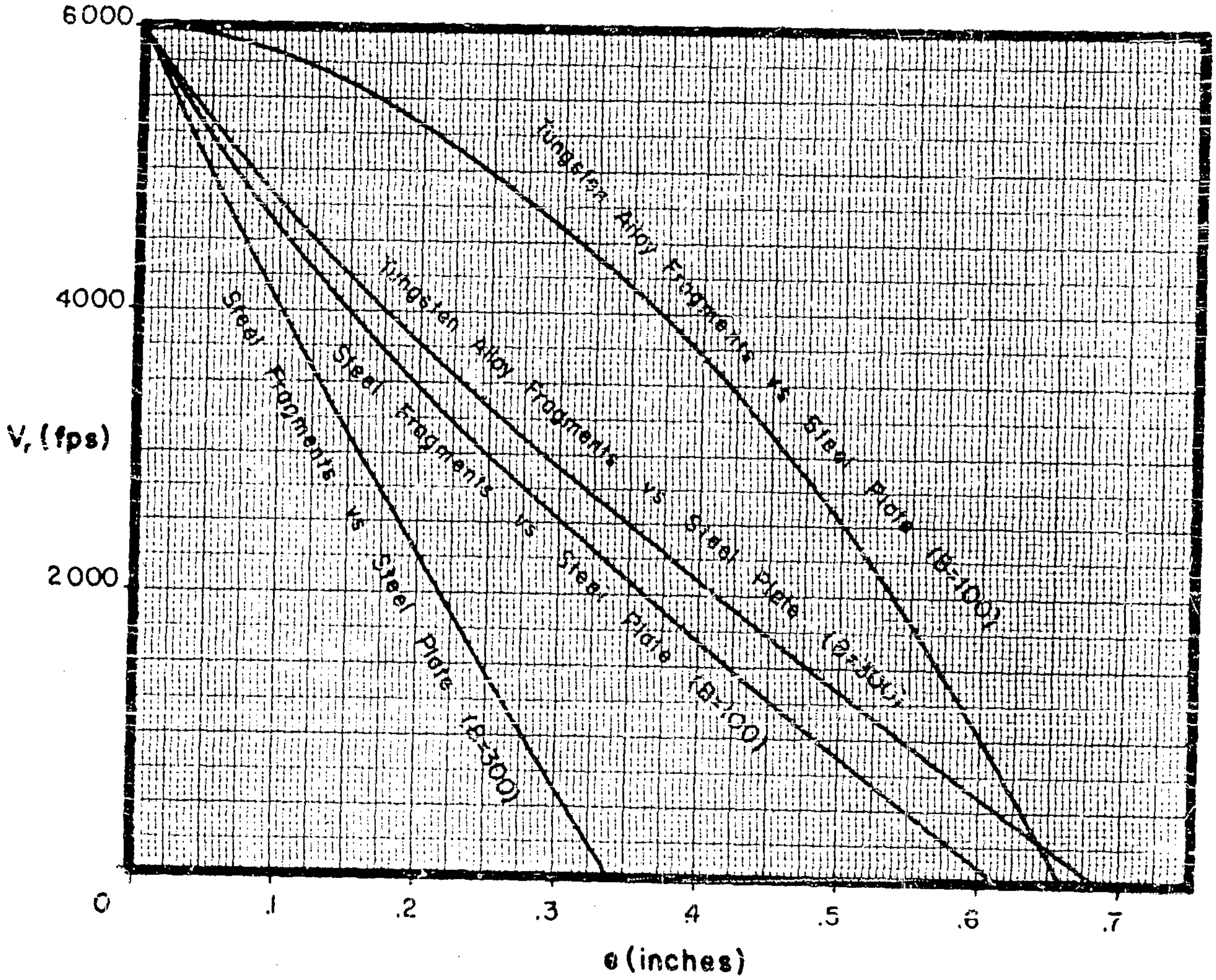
Fragment:
Type: BRL Pre-formed
Size: 300 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Steel
Obliquity: 60°
Striking Velocity: 6000 fps

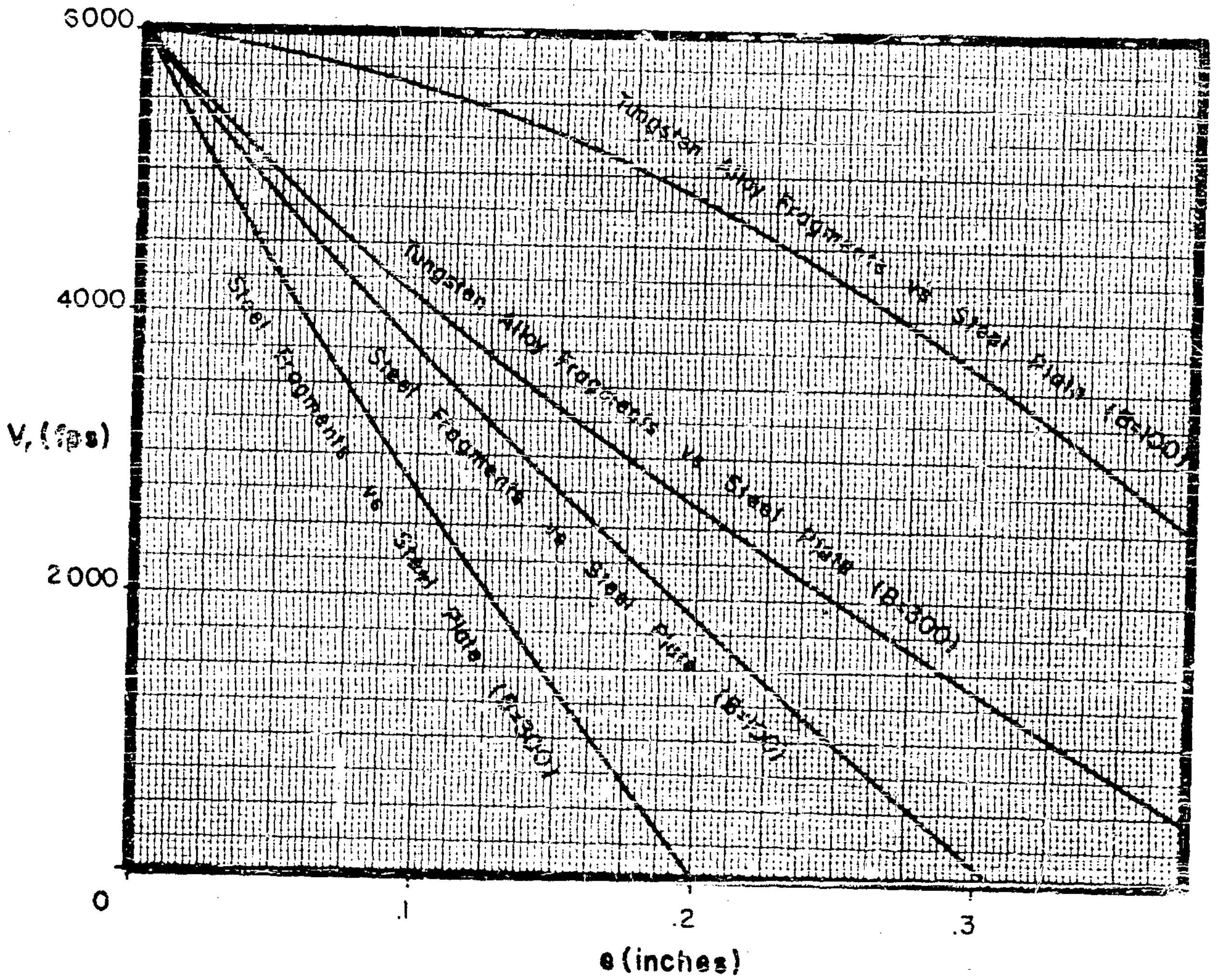
Fragment:
Type: BRL Pre-formed
Size: 300 grains



Residual Velocity vs Plate Thickness for Selected Combinations of Fragment Weight, Angle of Obliquity, and Striking Velocity

Plate Material: Steel
Obliquity: 70°
Striking Velocity: 6000 fps

Fragment:
Type: BRL Pre-formed
Size: 300 grains



APPENDIX VIII

Comparison of the Performance of Steel and Tungsten Alloy Fragments Impacting on Steel Plate

B. Plate Thickness vs Fragment Weight for Selected Combinations of V_o and Angle of Obliquity

Plate Thickness vs Fragment Weight for Selected Combinations of V_o and Angle of Obliquity

Plate Material : Steel

V_o : 2000 fps

Obliquity : 0°

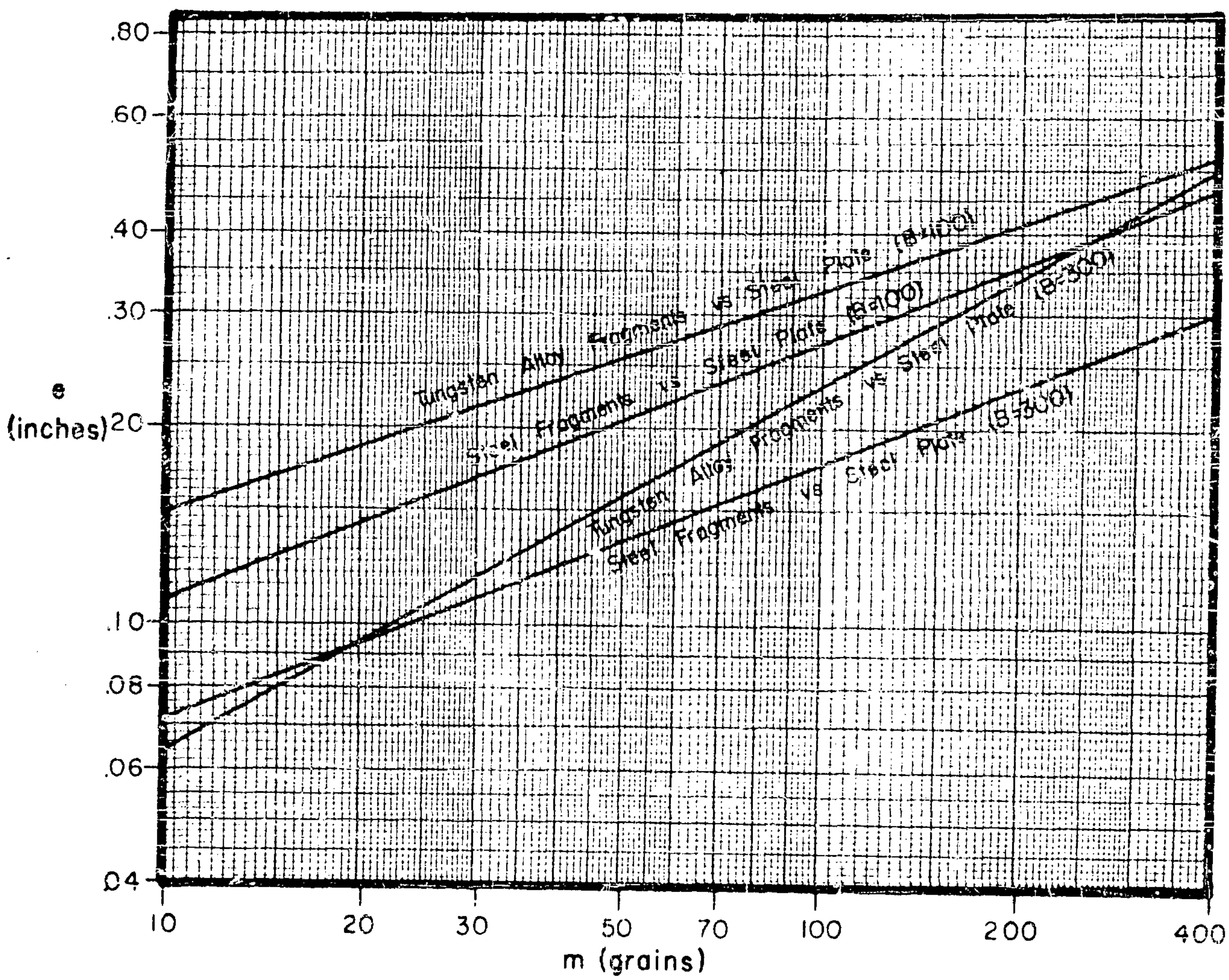


Plate Thickness vs Fragment Weight for Selected Combinations of V_o and Angle of Obliquity

Plate Material : Steel

V_o : 2000 fps

Obliquity : 60°

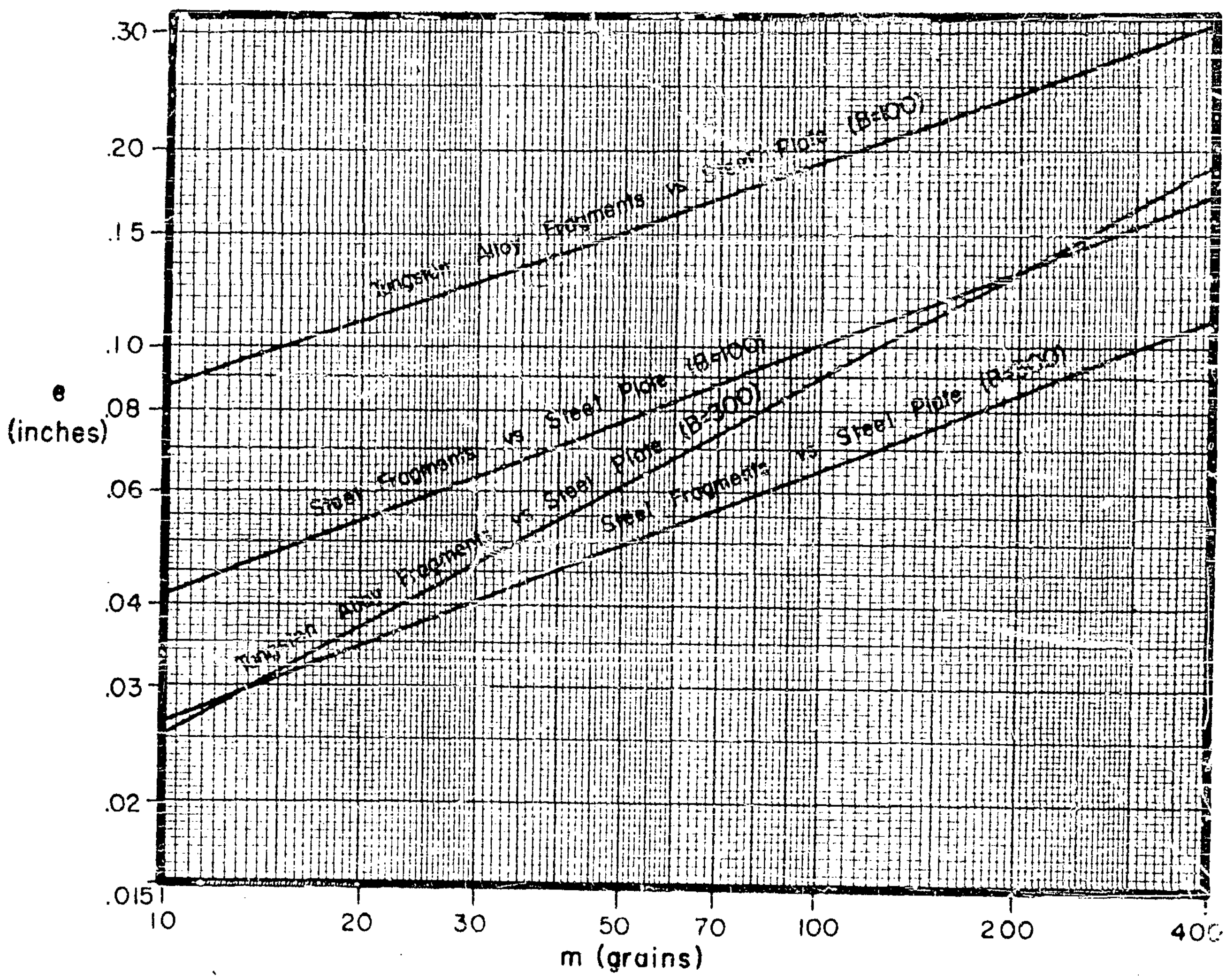


Plate Thickness vs Fragment Weight for Selected Combinations of V_o and Angle of Obliquity

Plate Material : Steel

V_o : 2000 fps

Obliquity : 70°

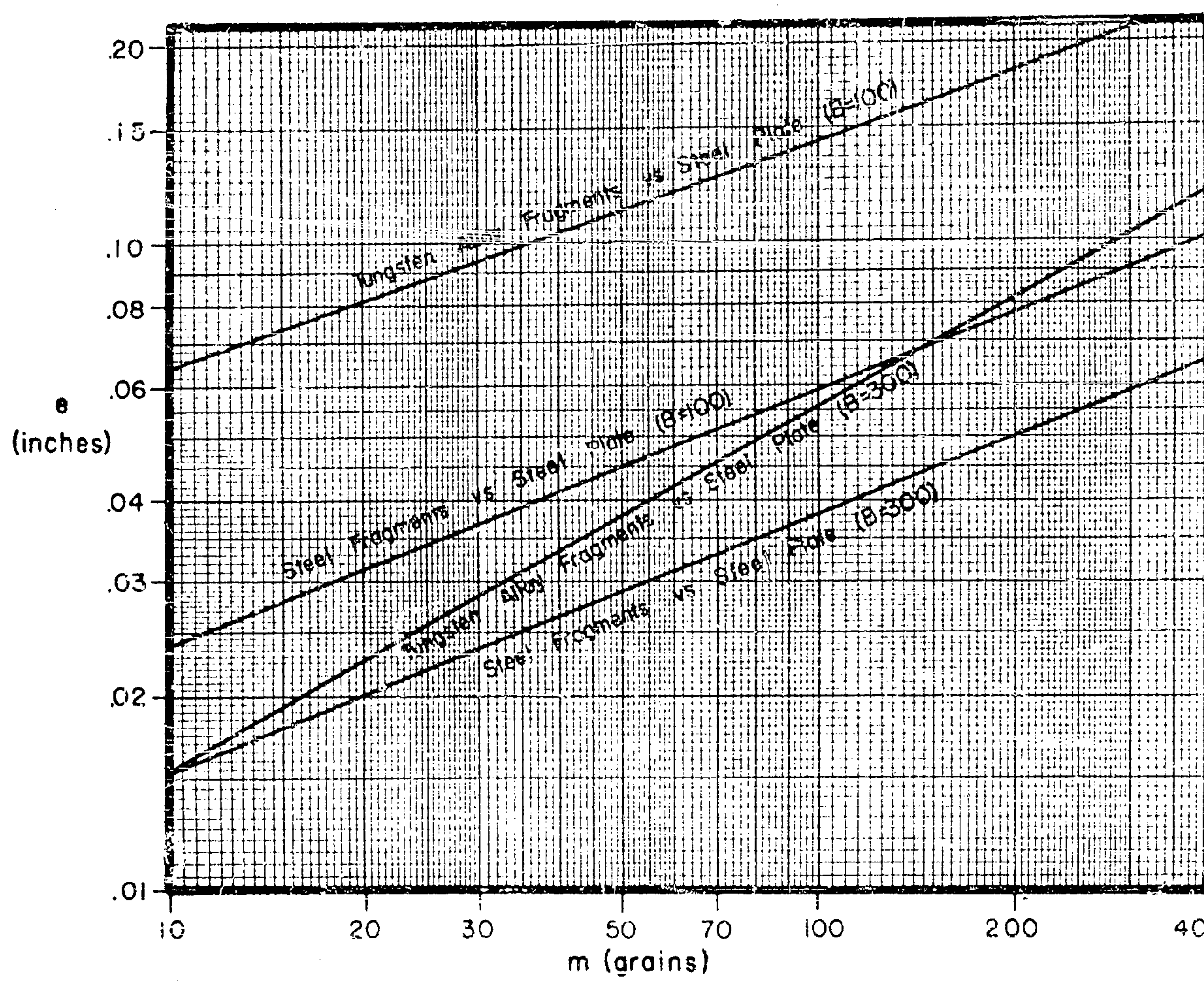


Plate Thickness vs Fragment Weight for Selected Combinations of V_o and Angle of Obliquity

Plate Material : Steel

V_o : 4000 fps

Obliquity : 0°

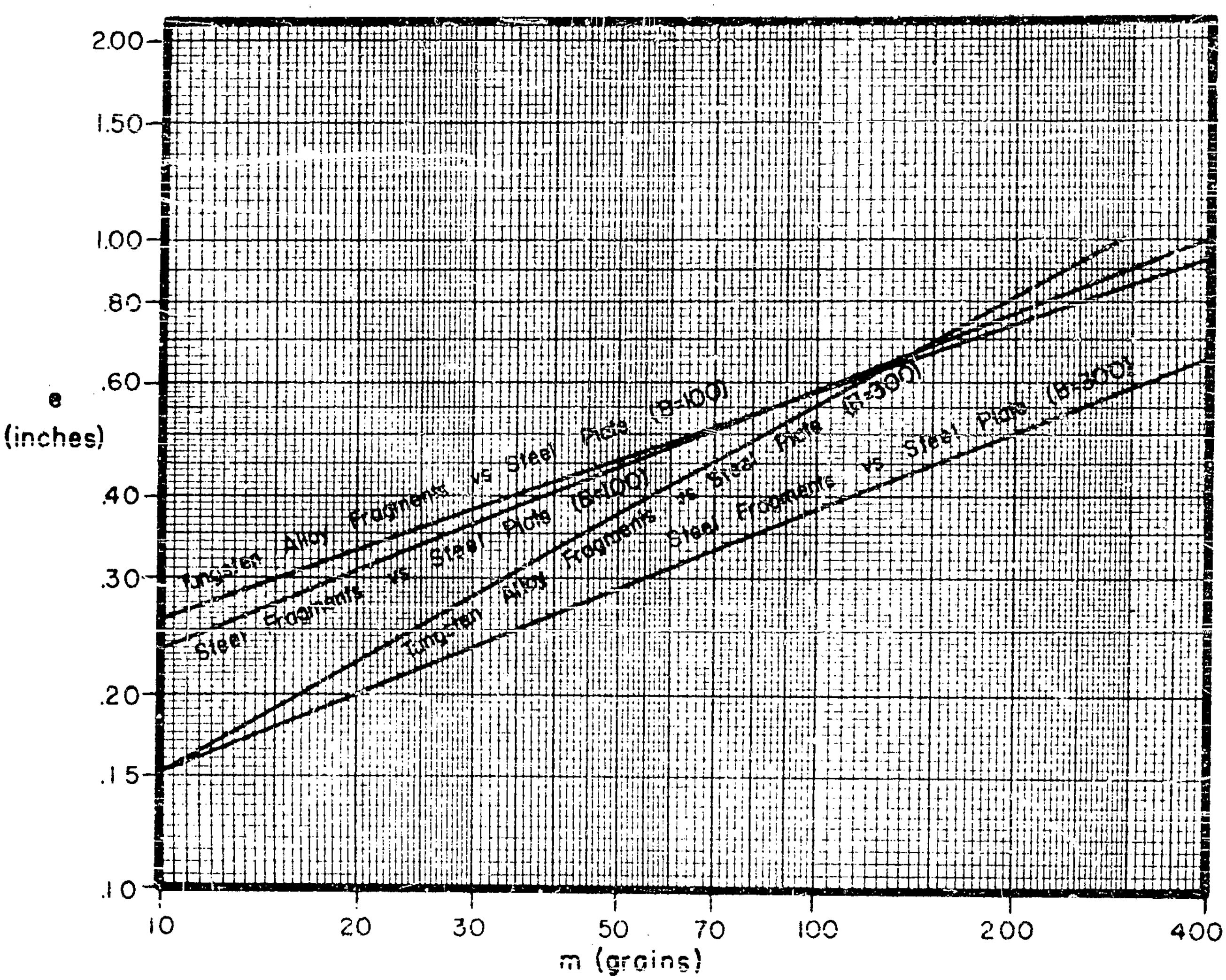


Plate Thickness vs Fragment Weight for Selected Combinations of V_o and Angle of Obliquity

Plate Material : Steel

V_o : 4000 fps

Obliquity : 60°

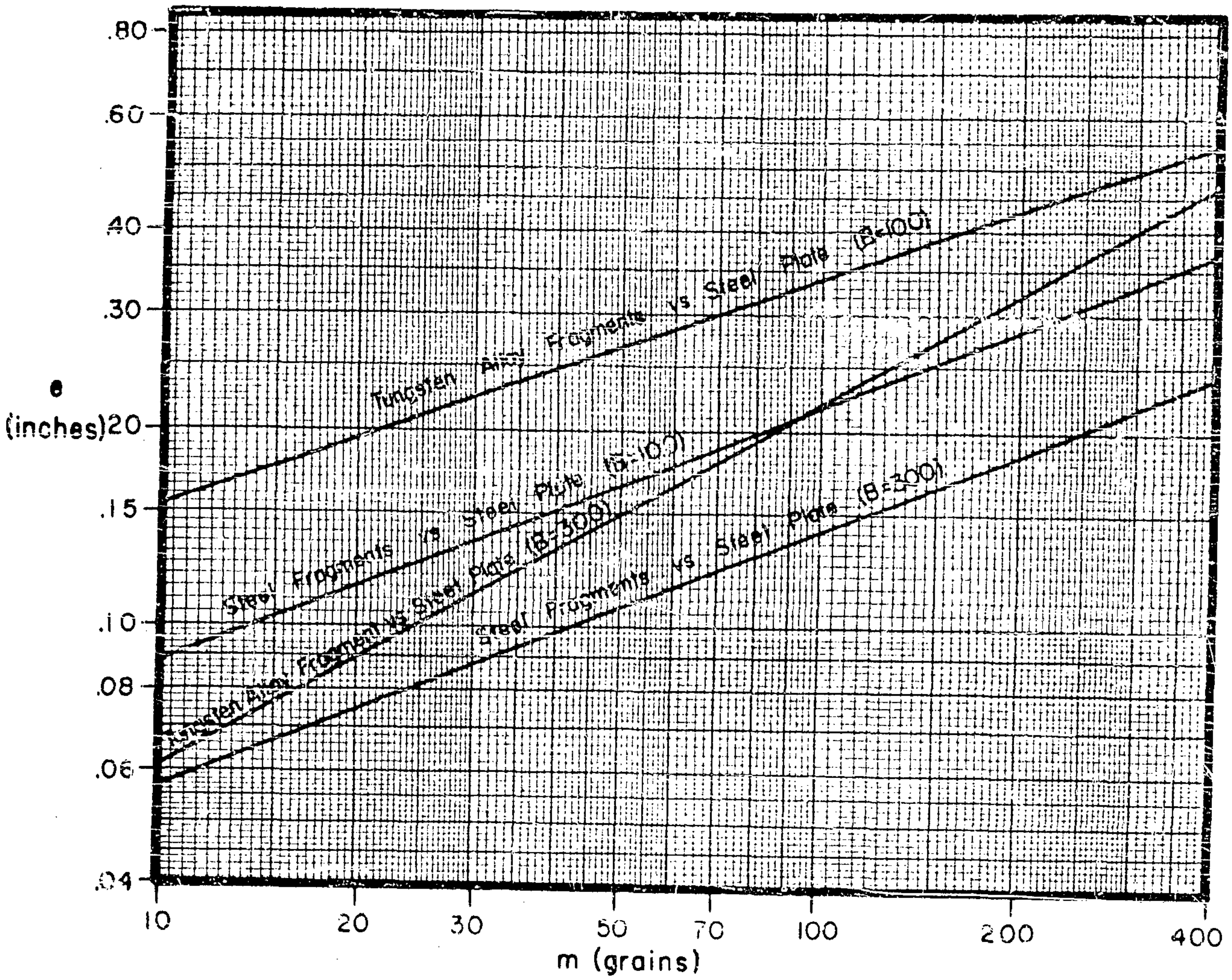


Plate Thickness vs Fragment Weight for Selected Combinations of V_o and Angle of Obliquity

Plate Material : Steel

V_o : 4000 fps

Obliquity : 70°

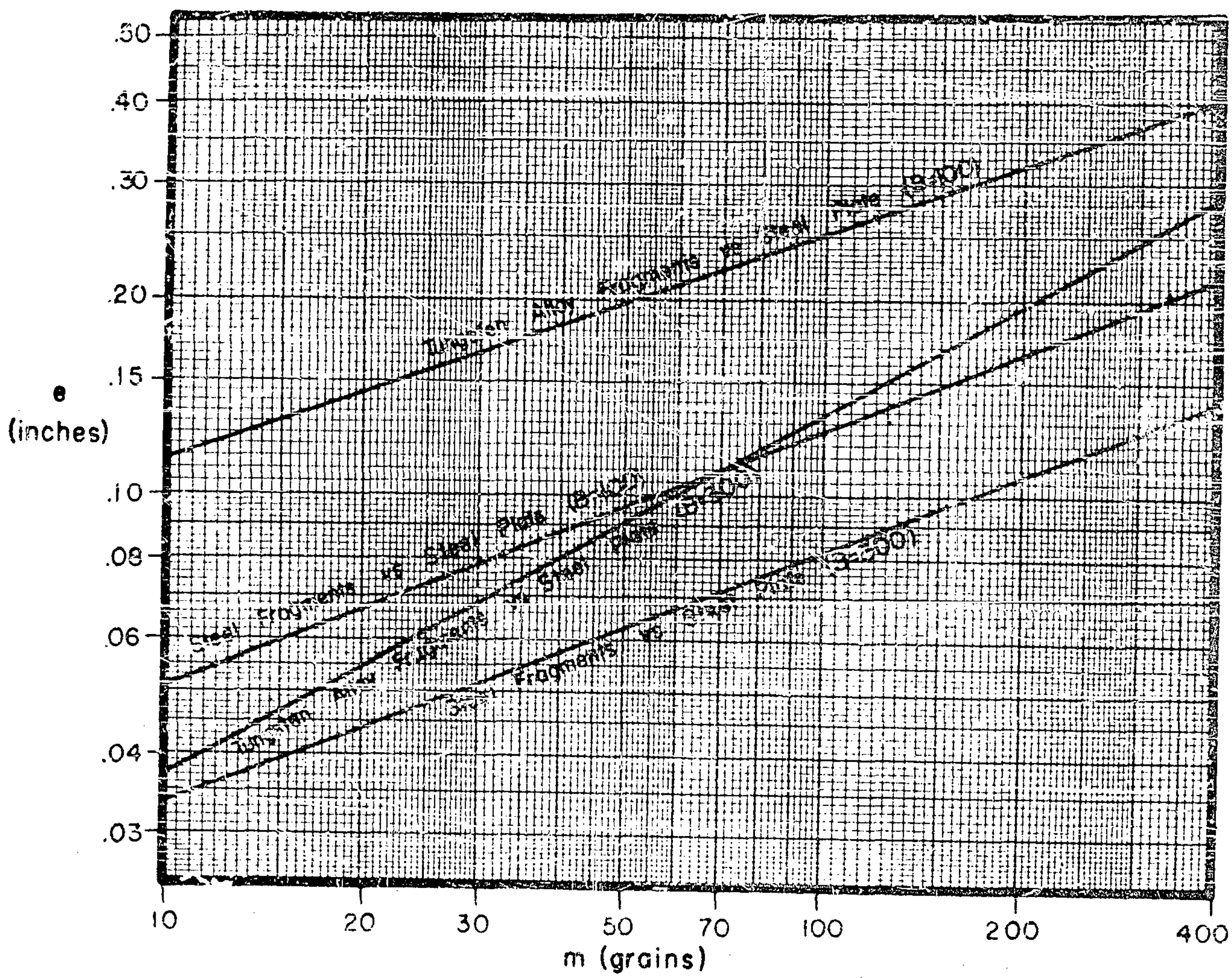


Plate Thickness vs Fragment Weight for Selected Combinations of V_o and Angle of Obliquity

Plate Material : Steel

V_o : 6000 fps

Obliquity : 0°

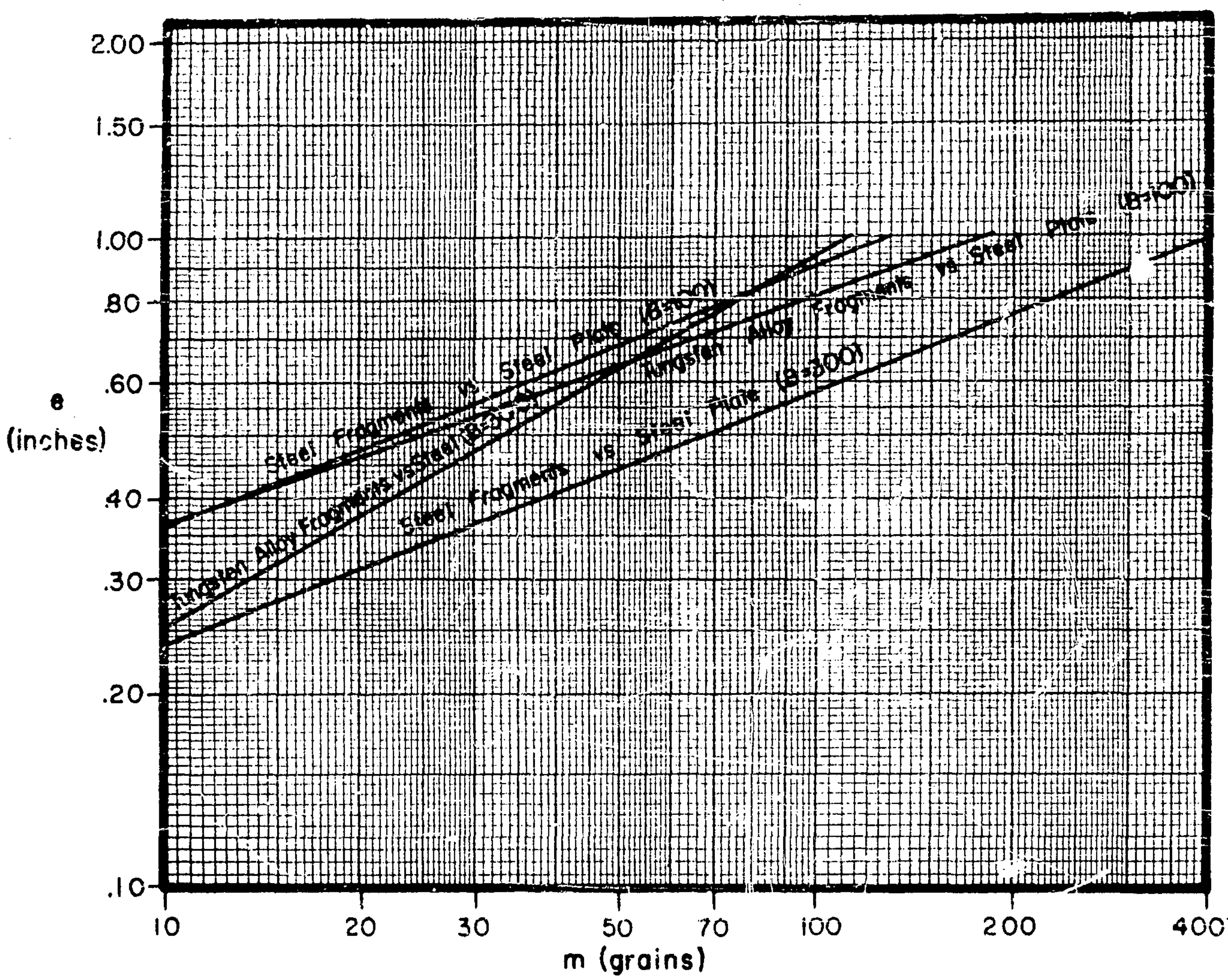


Plate Thickness vs Fragment Weight for Selected Combinations of V_o and Angle of Obliquity

Plate Material : Steel

V_o : 6000 fps

Obliquity : 60°

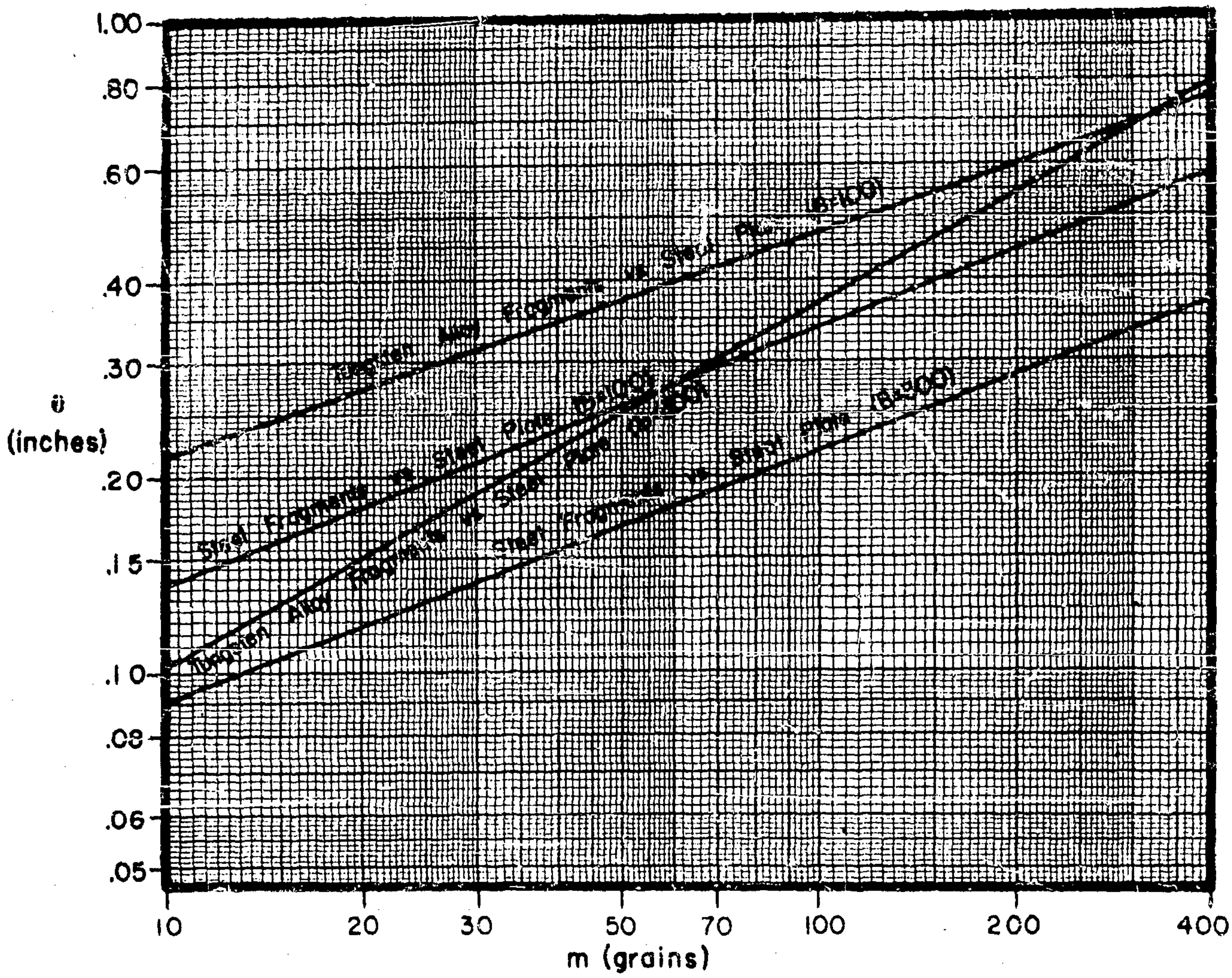
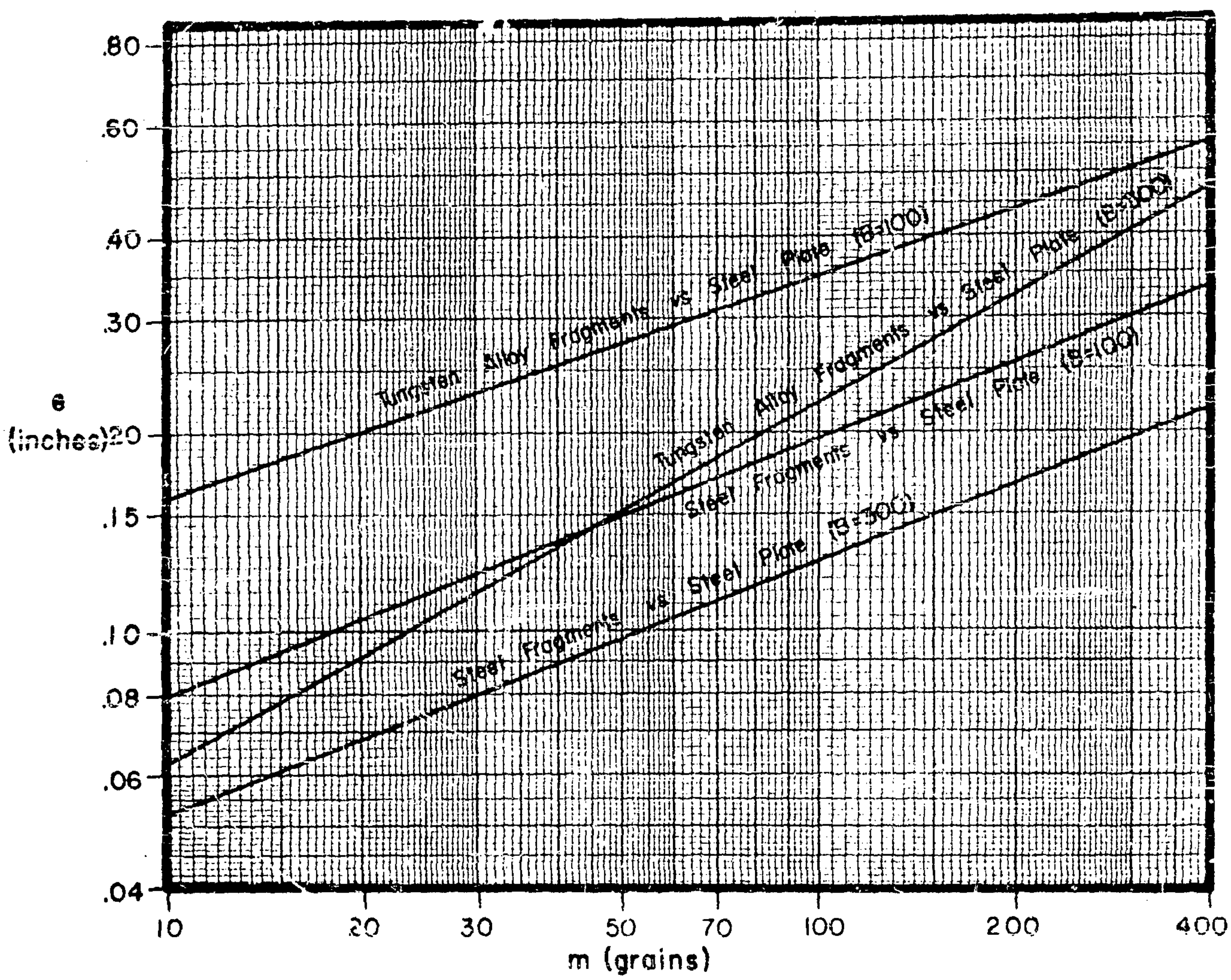


Plate Thickness vs Fragment Weight for Selected Combinations of V_o and Angle of Obliquity

Plate Material : Steel

V_o : 6000 fps

Obliquity : 70°



APPENDIX VIII

Comparison of the Performance of Steel and Tungsten Alloy Fragments Impacting on Steel Plate

C. $(V_o)_W$ / $(V_o)_S$ vs Plate Thickness for Selected Obliquities; B=100

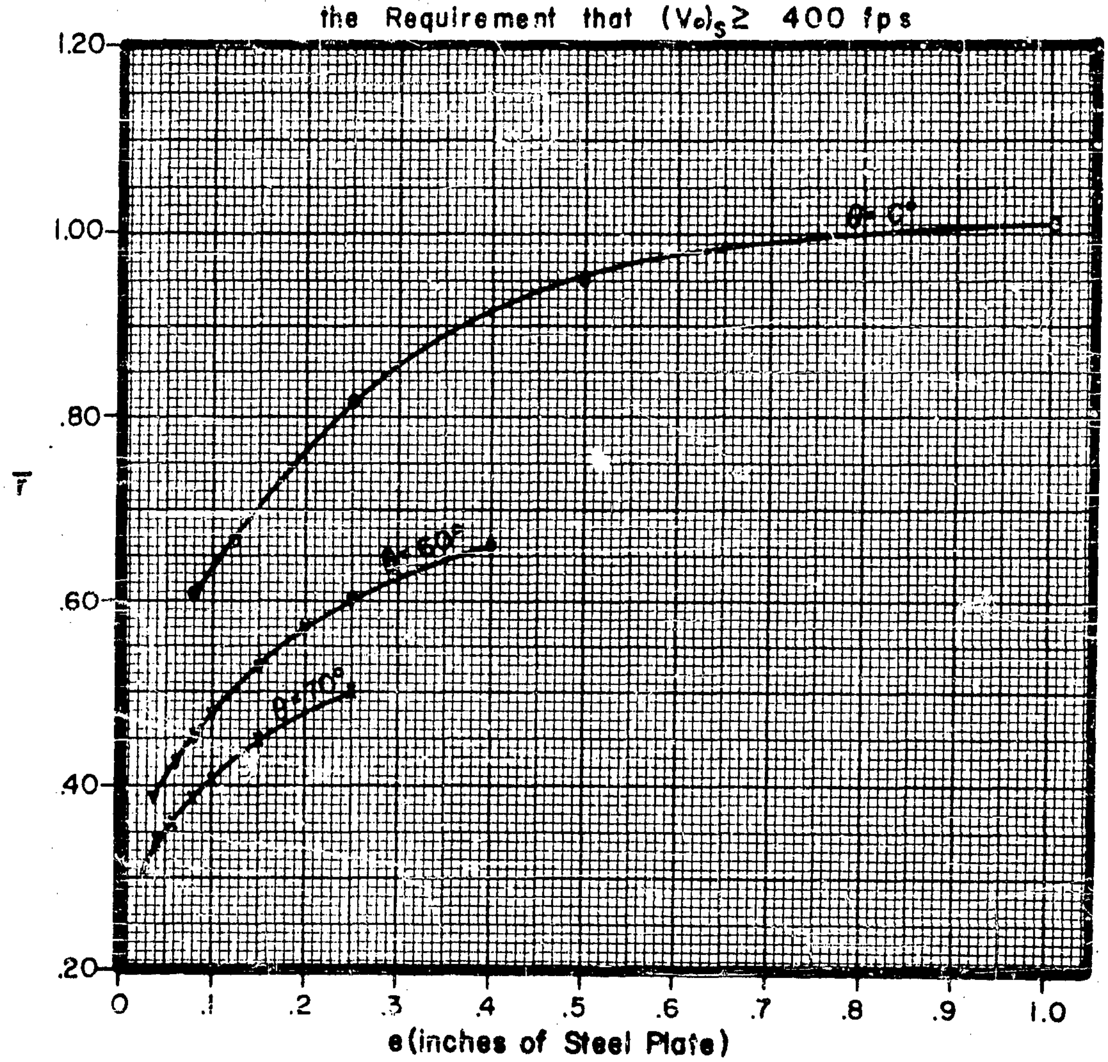
Comparison of Steel, Tungsten Alloy Fragments Impacting on Steel Plate (B= 100)

$\bar{r}$ vs e for Three Obliquities

NOTE: 1. $r = \frac{(V_o)_W}{(V_o)_S}$

2. $\bar{r}$ is the Average of the Values of r Corresponding to Selected Values of Fragment Weights for Any Given Set of Values of Obliquity and Material Thickness

3. Parameter Combinations Selected to Meet the Requirement that $(V_o)_S \geq 400$ fps



APPENDIX VIII

Comparison of the Performance of Steel and Tungsten Alloy Fragments

Impacting on Steel Plate

D. $(V_o)_W$ / $(V_o)_S$ vs Plate Thickness for Selected Obliquities ; B=300

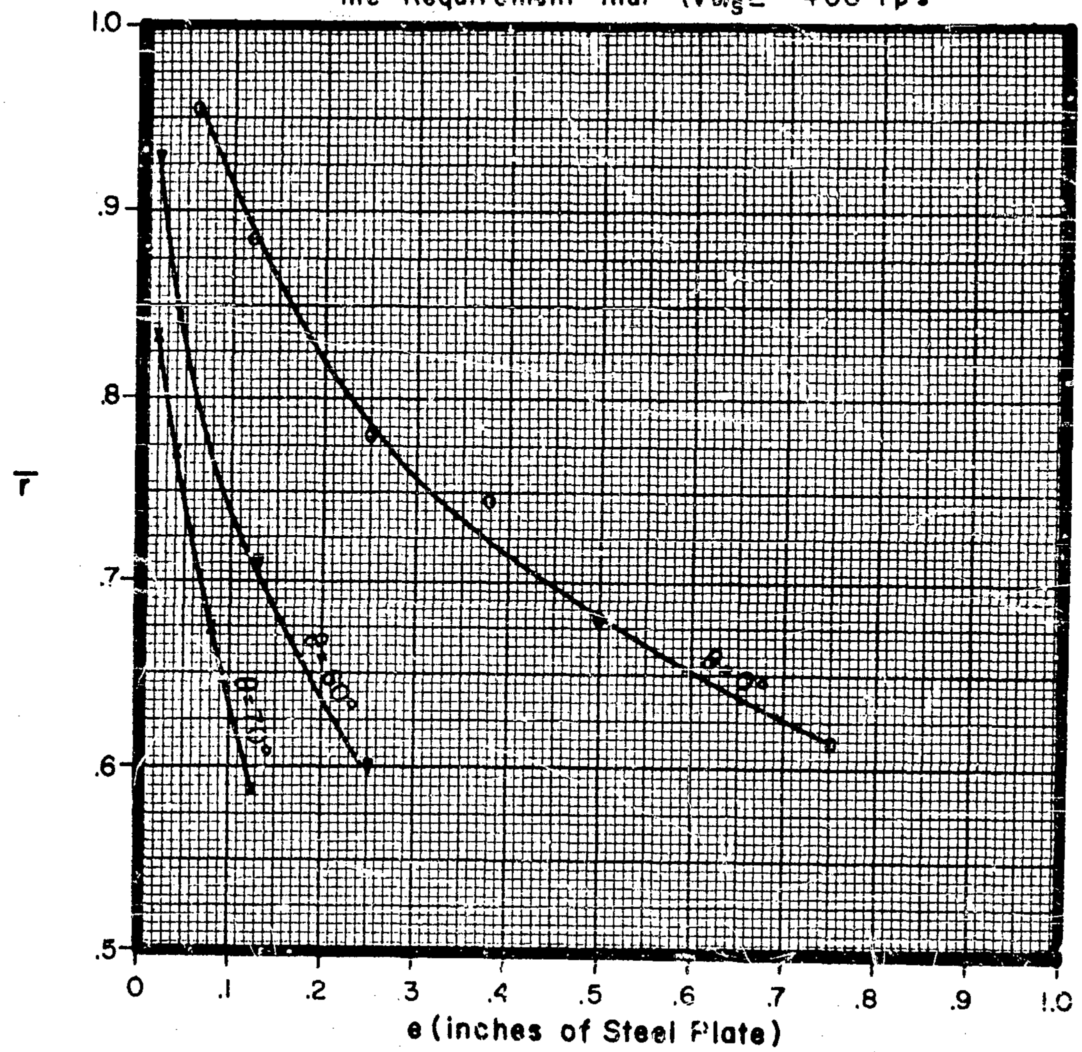
Comparison of Steel, Tungsten Alloy Fragments Impacting on Steel Plate (B = 300)

$\bar{r}$ vs e for Three Obliquities

NOTE: 1. $r = \frac{(V_o)_w}{(V_o)_s}$

2. $\bar{r}$ is the Average of the Values of r Corresponding to Selected Values of Fragment Weights for Any Given Set of Values of Obliquity and Material Thickness

3. Parameter Combinations Selected to Meet the Requirement that $(V_o)_s \geq$ 400 fps



APPENDIX VIII

Comparison of the Performance of Steel and Tungsten Alloy Fragments Impacting on Steel Plate

E. $(V_r)_W$ / $(V_r)_S$ vs Plate Thickness for Selected Obliquities; B=100

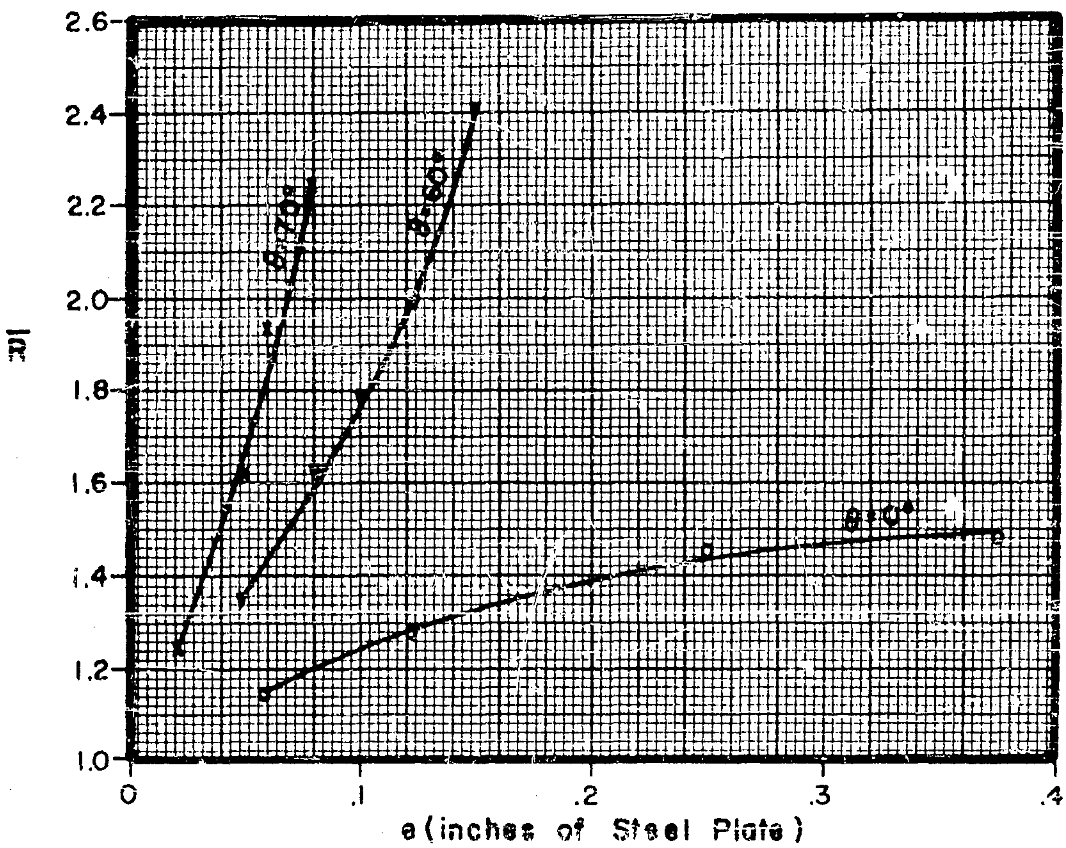
Comparison of Steel, Tungsten Alloy Fragments Impacting on Steel Plate (B = 100)

$\bar{R}$ vs e for Three Obliquities

NOTE: 1. $R = \frac{(V_r)_W}{(V_r)_S}$

2. $\bar{R}$ is the Average of the Values of R for Various Fragment Weights and Striking Velocities; thus $\bar{R}$ Depends Only on e and θ

3. Parameter Combinations Selected to Meet the Requirement that $(V_r)_S \geq 1000$ fps



APPENDIX VIII

Comparison of the Performance of Steel and Tungsten Alloy Fragments

Impacting on Steel Plate

F. $(V_r)_W$ / $(V_r)_S$ vs Plate Thickness for Selected Obliquities; B=300

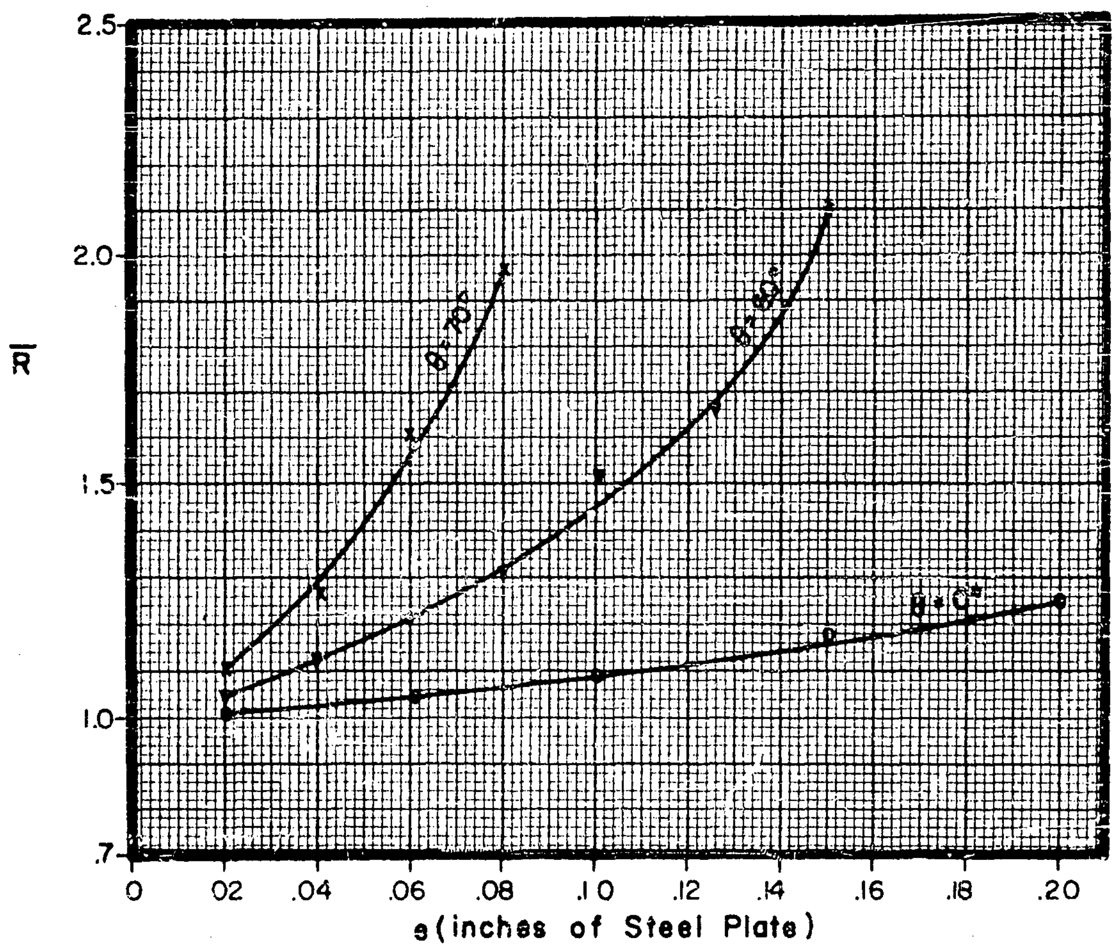
Comparison of Steel, Tungsten Alloy Fragments Impacting on Steel Plate (B = 300)

$\overline{R}$ vs e for Three Obliquities

NOTE: 1. $R = \frac{(V_r)_w}{(V_r)_s}$

2. $\overline{R}$ is the Average of the Values of R for Various Fragment Weights and Striking Velocities; thus $\overline{R}$ Depends Only on e and θ

3. Parameter Combinations Selected to Meet the Requirement that $(V_r)_s \geq 1000$ fps



APPENDIX IX

Other Baliistic Analysis Laboratory Reports on Penetration

The first report on penetration issued by this laboratory was published in September 1954 as Technical Report No. 14, "A Suggested Technique for Predicting the Performance of Armor-Piercing Projectiles Acting on Rolled Homogeneous Armor".

A second report was published in July 1956 as Technical Report No. 25, "A Comparison of Various Materials in Their Resistance To Perforation by Steel Fragments; Empirical Relationships". In this second report, ballistic limit data for steel fragments impacting on a number of materials are analyzed. Empirical formulas are developed to permit estimates of the ballistic limit for wide ranges of combinations of impact parameters.

A third report was published in April 1958 as Technical Report No. 36, "A Study of Residual Velocity Data for Steel Fragments Impacting on Four Materials; Empirical Relationships". Empirical formulas of the same type are fitted to the data for each material, thereby relating residual velocity to important impact parameters. Three sets of graphs are constructed based on these formulas. These sets of graphs permit, in turn, (1) a comparison, on an equal weight basis, of the resistance of four materials under impact, using as a criterion, the loss in velocity experienced by the fragment during perforation, (2) a pictorial representation of the variation of fragment residual velocity with striking velocity for various thicknesses of materials under certain fixed conditions, and (3) the variation of protection velocity, approximated analytically, with fragment weight for various thicknesses of materials under certain fixed conditions.

APPENDIX X

Photographs of Unfired and Recovered Fragments

Photographs of [illegible] Fragments

Uranium

30 grains | 60 grains | 120 grains | 240 grains

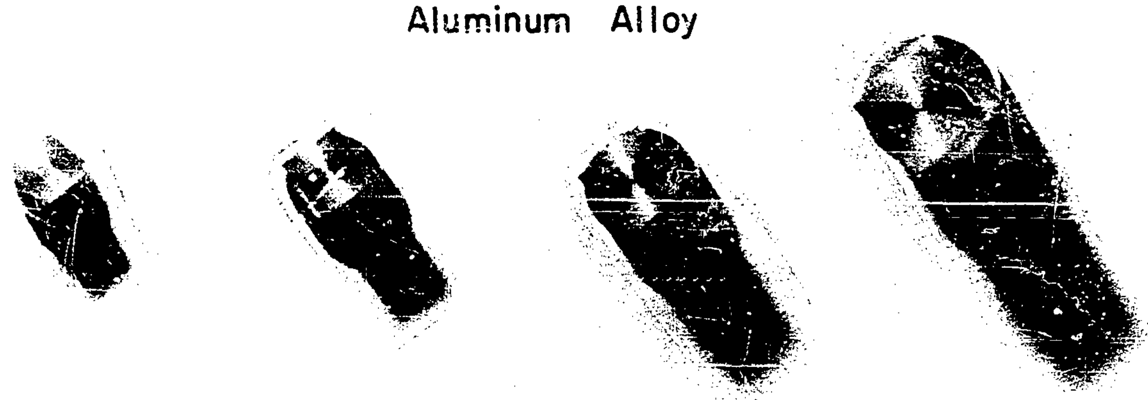
Tungsten Alloy

30 grains | 60 grains | 120 grains | 240 grains

Steel

30 grains | 60 grains | 120 grains | 240 grains

Aluminum Alloy



30 grains | 60 grains | 120 grains | 240 grains

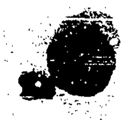
URANIUM FRAGMENTS RECOVERED AFTER IMPACT ON ALUMINUM ALLOY

V_s: 2610 fps
V_r: 1980 fps
m_s: 120 grns
$\bar{m}_r$: 119 grns
m_r: 119 grns
e : .125 in
θ : 70°

V_s: 3448 fps
V_r: 1867 fps
m_s: 120 grns
$\bar{m}_r$: 113 grns
m_r: 113 grns
e : .250 in
θ : 70°

V_s: 4075 fps
V_r: 2772 fps
m_s: 120 grns
$\bar{m}_r$: 94 grns
m_r: 93 grns
e : .750 in
θ : 0°

V_s: 3946 fps
V_r: 1966 fps
m_s: 120 grns
$\bar{m}_r$: 13 grns
m_r: 13 grns
e : .500 in
θ : 60°



V_s: 3859 fps
V_r: 1756 fps
m_s: 120 grns
$\bar{m}_r$: 70 grns
m_r: 68 grns
e : 1.00 in
θ : 0°

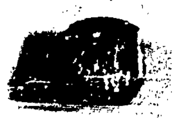
V_s: 2383 fps
V_r: 1643 fps
m_s: 30 grns
$\bar{m}_r$: 28 grns
m_r: 28 grns
e : .250 in
θ : 0°

V_s: 1449 fps
V_r: 1150 fps
m_s: 60 grns
$\bar{m}_r$: 60 grns
m_r: 60 grns
e : .063 in
θ : 70°

V_s: 2183 fps
V_r: 1621 fps
m_s: 60 grns
$\bar{m}_r$: 60 grns
m_r: 60 grns
e : .250 in
θ : 0°

V_s: 2235 fps
V_r: 1651 fps
m_s: 60 grns
$\bar{m}_r$: 59 grns
m_r: 59 grns
e : .125 in
θ : 60°

URANIUM FRAGMENTS RECOVERED AFTER IMPACT ON ALUMINUM ALLOY



V_s: 3820 fps
V_r: ~2400 fps
m_s: 240 grns
$\bar{m}_r$: 207 grns
m_r: 207 grns
e : 1.00 in
θ : 0°

V_s: 5062 fps
V_s: 1819 fps
m_s: 240 grns
$\bar{m}_r$: 96 grns
m_r: 32 grns
e : 1.5 in
θ : 0°

V_s: 4936 fps
V_s: 3171 fps
m_s: 240 grns
$\bar{m}_r$: 36 grns
m_r: 36 grns
e : .500 in
θ : 60°

V_s: 5270 fps
V_r: 1226 fps
m_s: 240 grns
$\bar{m}_r$: 29 grns
m_r: 29 grns
e : 1.00 in
θ : 60°

V_s: 5920 fps
V_r: 2198 fps
m_s: 120 grns
$\bar{m}_r$: 5 grns
m_r: 5 grns
e : .500 in
θ : 70°

V_s: 5284 fps
V_r: 3449 fps
m_s: 120 grns
$\bar{m}_r$: 54 grns
m_r: 16 grns
e : 1.00 in
θ : 0°

V_s: 2557 fps
V_r: 2216 fps
m_s: 120 grns
$\bar{m}_r$: 120 grns
m_r: 120 grns
e : .250 in
θ : 0°

V_s: 3101 fps
V_r: 2292 fps
m_s: 120 grns
$\bar{m}_r$: 103 grns
m_r: 103 grns
e : .500 in
θ : 0°

V_s: 2746 fps
V_r: 1733 fps
m_s: 120 grns
$\bar{m}_r$: 116 grns
m_r: 116 grns
e : .250 in
θ : 60°

URANIUM FRAGMENTS RECOVERED AFTER IMPACT ON ALUMINUM ALLOY

V_s : 2468 fps
V_r : 2140 fps
m_s : 240 grns
$\bar{m}_r$: 233 grns
m_r : 233 grns
e : .125 in
θ : 70°

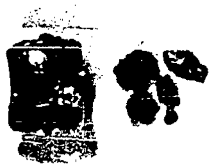
V_s : 3512 fps
V_r : 2753 fps
m_s : 240 grns
$\bar{m}_r$: 226 grns
m_r : 226 grns
e : .250 in
θ : 60°

V_s : 3633 fps
V_r : 2550 fps
m_s : 240 grns
$\bar{m}_r$: 186 grns
m_r : 74 grns
e : .375 in
θ : 60°

V_s : 2209 fps
V_r : ~2150 fps
m_s : 240 grns
$\bar{m}_r$: 240 grns
m_r : 240 grns
e : .063 in
θ : 0°

V_s : 2939 fps
V_r : 2244 fps
m_s : 240 grns
$\bar{m}_r$: 214 grns
m_r : 73 grns
e : .500 in
θ : 0°

V_s : 3635 fps
V_r : 2057 fps
m_s : 240 grns
$\bar{m}_r$: 130 grns
m_r : 130 grns
e : 1.00 in
θ : 0°



V_s : 3691 fps
V_r : 2504 fps
m_s : 240 grns
$\bar{m}_r$: 195 grns
m_r : 183 grns
e : .250 in
θ : 70°

V_s : 3859 fps
V_r : 1745 fps
m_s : 240 grns
$\bar{m}_r$: 63 grns
m_r : 37 grns
e : .375 in
θ : 70°

V_s : 4718 fps
V_r : 2628 fps
m_s : 240 grns
$\bar{m}_r$: 31 grns
m_r : 31 grns
e : .500 in
θ : 70°

URANIUM FRAGMENTS RECOVERED AFTER IMPACT ON ALUMINUM ALLOY

V_s : 1461 fps
V_r : 1111 fps
m_s : 30 grns
$\bar{m}_r$: 29 grns
m_r : 29 grns
e : .060 in
θ : 60°

V_s : 3590 fps
V_r : 2836 fps
m_s : 30 grns
$\bar{m}_r$: 27 grns
m_r : 27 grns
e : .125 in
θ : 60°

V_s : 3123 fps
V_r : 2144 fps
m_s : 30 grns
$\bar{m}_r$: 28 grns
m_r : 28 grns
e : .125 in
θ : 70°

V_s : 4629 fps
V_r : 3121 fps
m_s : 30 grns
$\bar{m}_r$: 8 grns
m_r : 8 grns
e : .500 in
θ : 0°

V_s : 4838 fps
V_r : 3442 fps
m_s : 30 grns
$\bar{m}_r$: 1 grn
m_r : 1 grn
e : .250 in
θ : 60°

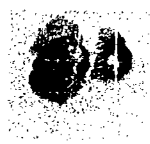
V_s : 5380 fps
V_r : 2008 fps
m_s : 30 grns
$\bar{m}_r$: 1 grn
m_r : 1 grn
e : .500 in
θ : 60°

URANIUM FRAGMENTS RECOVERED AFTER IMPACT ON ALUMINUM ALLOY

V_s : 2774 fps
V_r : 2024 fps
m_s : 60 grns
$\bar{m}_r$: 53 grns
m_r : 53 grns
e : .375 in
θ : 0^o

V_s : 3437 fps
V_r : 2373 fps
m_s : 60 grns
$\bar{m}_r$: 46 grns
m_r : 46 grns
e : .500 in
θ : 0^o

V_s : 3363 fps
V_r : 1259 fps
m_s : 60 grns
$\bar{m}_r$: 30 grns
m_r : 30 grns
e : .750 in
θ : 0^o



V_s : 3487 fps
V_r : 1098 fps
m_s : 60 grns
$\bar{m}_r$: 35 grns
m_r : 30 grns
e : .250 in
θ : 70^o

V_s : 3430 fps
V_r : 2435 fps
m_s : 60 grns
$\bar{m}_r$: 27 grns
m_r : 27 grns
e : .250 in
θ : 60^o

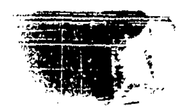
V_s : 2880 fps
V_r : 1969 fps
m_s : 60 grns
$\bar{m}_r$: 53 grns
m_r : 53 grns
e : .125 in
θ : 70^o

TUNGSTEN ALLOY FRAGMENTS RECOVERED AFTER IMPACT ON ALUMINUM ALLOY



V_s :	1981 fps	2199 fps	2147 fps
V_r :	0	0	0
m_s :	240 grns	240 grns	240 grns
$\bar{m}_r$:	241 grns	240 grns	177 grns
m_r :	199 grns	240 grns	129 grns
e :	.250 in	.500 in	.250 in
θ :	70°	60°	70°





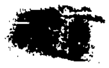
V_s :	3174 fps	4430 fps	3635 fps
V_r :	3091 fps	1748 fps	2488 fps
m_s :	120 grns	60 grns	240 grns
$\bar{m}_r$:	92 grns	49 grns	230 grns
m_r :	92 grns	49 grns	230 grns
e :	.091 in	.500 in	.250 in
θ :	0°	60°	70°



V_s :	3147 fps	4884 fps	4910 fps
V_r :	2617 fps	4412 fps	4376 fps
m_s :	120 grns	120 grns	120 grns
$\bar{m}_r$:	100 grns	83 grns	92 grns
m_r :	100 grns	83 grns	58 grns
e :	.091 in	.091 in	.091 in
θ :	70°	70°	70°

TUNGSTEN ALLOY FRAGMENTS RECOVERED AFTER IMPACT ON ALUMINUM ALLOY

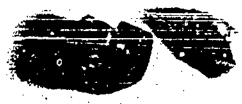
V_s: 3218 fps
V_r: 1886 fps
m_s: 60 grns
$\bar{m}_r$: 56 grns
m_r: 56 grns
e : .250 in
θ : 60°



V_s: 3158 fps
V_r: 1800 fps
m_s: 60 grns
$\bar{m}_r$: 59 grns
m_r: 59 grns
e : .250 in
θ : 60°

V_s: 2941 fps
V_r: 1929 fps
m_s: 120 grns
$\bar{m}_r$: 115 grns
m_r: 99 grns
e : .250 in
θ : 60°

V_s: 3012 fps
V_r: 2167 fps
m_s: 120 grns
$\bar{m}_r$: 118 grns
m_r: 118 grns
e : .250 in
θ : 60°



V_s: 3719 fps
V_r: 2232 fps
m_s: 240 grns
$\bar{m}_r$: 174 grns
m_r: 126 grns
e : .500 in
θ : 60°

V_s: 3733 fps
V_r: 2516 fps
m_s: 240 grns
$\bar{m}_r$: 179 grns
m_r: 179 grns
e : .500 in
θ : 60°

V_s: 4918 fps
V_r: 4877 fps
m_s: 120 grns
$\bar{m}_r$: 72 grns
m_r: 72 grns
e : .091 in
θ : 0°

V_s: 4871 fps
V_r: 4840 fps
m_s: 120 grns
$\bar{m}_r$: 95 grns
m_r: 95 grns
e : .091 in
θ : 0°

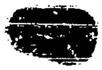
V_s: 3153 fps
V_r: 3051 fps
m_s: 120 grns
$\bar{m}_r$: 78 grns
m_r: 78 grns
e : .091 in
θ : 0°

TUNGSTEN ALLOY FRAGMENTS RECOVERED AFTER IMPACT ON ALUMINUM ALLOY

V_s : 4150 fps
V_r : 0
m_s : 30 grns
$\bar{m}_r$: 23 grns
m_r : 23 grns
e : .500 in
θ : 60°

V_s : 2450 fps
V_r : 0
m_s : 30 grns
$\bar{m}_r$: 30 grns
m_r : 30 grns
e : .500 in
θ : 0°

V_s : 1983 fps
V_r : 0
m_s : 60 grns
$\bar{m}_r$: 60 grns
m_r : 60 grns
e : .250 in
θ : 60°



V_s : 2826 fps
V_r : 0
m_s : 60 grns
$\bar{m}_r$: 60 grns
m_r : 60 grns
e : .500 in
θ : 45°

V_s : 3381 fps
V_r : 0
m_s : 60 grns
$\bar{m}_r$: 26 grns
m_r : 16 grns
e : .500 in
θ : 60°

V_s : 4742 fps
V_r : 0
m_s : 60 grns
$\bar{m}_r$: 48 grns
m_r : 48 grns
e : 1.00 in
θ : 0°

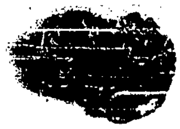
V_s : 2881 fps
V_r : 0
m_s : 120 grns
$\bar{m}_r$: 106 grns
m_r : 106 grns
e : 1.00 in
θ : 0°

V_s : 3943 fps
V_r : 0
m_s : 120 grns
$\bar{m}_r$: 80 grns
m_r : 80 grns
e : 1.00 in
θ : 0°

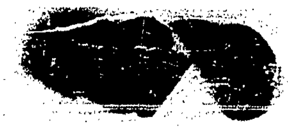
V_s : 1243 fps
V_r : 0
m_s : 240 grns
$\bar{m}_r$: 240 grns
m_r : 240 grns
e : .091 in
θ : 80°

CONFIDENTIAL

TUNGSTEN ALLOY FRAGMENTS RECOVERED AFTER IMPACT ON ALUMINUM ALLOY



V_s: 3754 fps
V_r: 3492 fps
m_s: 240 grns
$\bar{m}_r$: 225 grns
m_r: 225 grns
e : .250 in
θ : 0°



V_s: 3769 fps
V_r: 3500 fps
m_s: 240 grns
$\bar{m}_r$: 230 grns
m_r: 145 grns
e : .250 in
θ : 0°

V_s: 3724 fps
V_r: 2486 fps
m_s: 240 grns
$\bar{m}_r$: 225 grns
m_r: 225 grns
e : 1.00 in
θ : 0°

V_s: 3722 fps
V_r: 2391 fps
m_s: 240 grns
$\bar{m}_r$: 179 grns
m_r: 156 grns
e : 1.00 in
θ : 0°

V_s: 3123 fps
V_r: 2007 fps
m_s: 120 grns
$\bar{m}_r$: 110 grns
m_r: 110 grns
e : 1.00 in
θ : 0°

V_s: 2867 fps
V_r: 2501 fps
m_s: 60 grns
$\bar{m}_r$: 59 grns
m_r: 59 grns
e : .250 in
θ : 0°

V_s: 2867 fps
V_r: 2420 fps
m_s: 60 grns
$\bar{m}_r$: 59 grns
m_r: 59 grns
e : .250 in
θ : 0°

V_s: 3968 fps
V_r: 3564 fps
m_s: 60 grns
$\bar{m}_r$: 56 grns
m_r: 56 grns
e : .250 in
θ : 0°

V_s: 4250 fps
V_r: 3954 fps
m_s: 60 grns
$\bar{m}_r$: 46 grns
m_r: 46 grns
e : .250 in
θ : 0°

CONFIDENTIAL

TUNGSTEN ALLOY FRAGMENTS RECOVERED AFTER IMPACT ON STEEL (B~100)

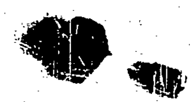
V_s : 1950 fps
V_r : 0
m_s : 60 grns
$\bar{m}_r$: 55 grns
m_r : 55 grns
e : .250 in
θ : 0^o

V_s : 1588 fps
V_r : 0
m_s : 60 grns
$\bar{m}_r$: 53 grns
m_r : 53 grns
e : .125 in
θ : 60^o

V_s : 3267 fps
V_r : 0
m_s : 120 grns
$\bar{m}_r$: 106 grns
m_r : 106 grns
e : .500 in
θ : 0^o

V_s : 2284 fps
V_r : 1734 fps
m_s : 120 grns
$\bar{m}_r$: 108 grns
m_r : 108 grns
e : .125 in
θ : 0^o

V_s : 3087 fps
V_r : 2100 fps
m_s : 120 grns
$\bar{m}_r$: 39 grns
m_r : 23 grns
e : .125 in
θ : 60^o



V_s : 3619 fps
V_r : 1040 fps
m_s : 240 grns
$\bar{m}_r$: 57 grns
m_r : 46 grns
e : .500 in
θ : 0^o

TUNGSTEN ALLOY FRAGMENTS RECOVERED AFTER IMPACT ON STEEL (B ~ 300)

V_s: 1030 fps
V_r: 0
m_s: 30 grns
$\bar{m}_r$: 30 grns
m_r: 30 grns
e : .06 in
θ : 0°

V_s: 1791 fps
V_r: 0
m_s: 30 grns
$\bar{m}_r$: 30 grns
m_r: 30 grns
e : .125 in
θ : 0°

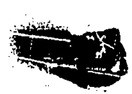
V_s: 2488 fps
V_r: 0
m_s: 30 grns
$\bar{m}_r$: 11 grns
m_r: 11 grns
e : .06 in
θ : 60°

V_s: 1234 fps
V_r: 0
m_s: 60 grns
$\bar{m}_r$: 59 grns
m_r: 59 grns
e : .125 in
θ : 0°

V_s: 3054 fps
V_r: 1492 fps
m_s: 60 grns
$\bar{m}_r$: 54 grns
m_r: 54 grns
e : .130 in
θ : 0°

V_s: 1981 fps
V_r: 0
m_s: 60 grns
$\bar{m}_r$: 49 grns
m_r: 49 grns
e : .250 in
θ : 0°

V_s: 4414 fps
V_r: 3100 fps
m_s: 60 grns
$\bar{m}_r$: 26 grns
m_r: 26 grns
e : .250 in
θ : 0°



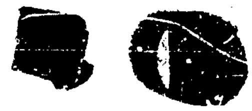
V_s: 947 fps
V_r: 0
m_s: 120 grns
$\bar{m}_r$: 117 grns
m_r: 117 grns
e : .125 in
θ : 0°

V_s: 1886 fps
V_r: 0
m_s: 120 grns
$\bar{m}_r$: 103 grns
m_r: 76 grns
e : .250 in
θ : 0°

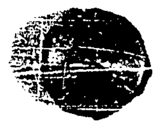
TUNGSTEN ALLOY FRAGMENTS RECOVERED AFTER IMPACT ON STEEL (B ~ 300)

V_s : 3584 fps
V_r : 0
m_s : 120 grns
$\bar{m}_r$: 106 grns
m_r : 106 grns
e : .500 in
θ : 0°

V_s : 4942 fps
V_r : 2160 fps
m_s : 120 grns
$\bar{m}_r$: 54 grns
m_r : 54 grns
e : .500 in
θ : 0°



V_s : 3835 fps
V_r : 3675 fps
m_s : 240 grns
$\bar{m}_r$: 222 grns
m_r : 130 grns
e : .125 in
θ : 0°



V_s : 2288 fps
V_r : 0
m_s : 240 grns
$\bar{m}_r$: 230 grns
m_r : 230 grns
e : .500 in
θ : 0°

V_s : 3724 fps
V_r : 1670 fps
m_s : 240 grns
$\bar{m}_r$: 117 grns
m_r : 93 grns
e : .500 in
θ : 0°

V_s : 3870 fps
V_r : 3225 fps
m_s : 240 grns
$\bar{m}_r$: 137 grns
m_r : 137 grns
e : .125 in
θ : 60°

V_s : 3956 fps
V_r : 3400 fps
m_s : 240 grns
$\bar{m}_r$: 168 grns
m_r : 37 grns
e : .125 in
θ : 60°

V_s : 3947 fps
V_r : 1665 fps
m_s : 240 grns
$\bar{m}_r$: 133 grns
m_r : 72 grns
e : .250 in
θ : 60°

V_s : 3898 fps
V_r : 2005 fps
m_s : 240 grns
$\bar{m}_r$: 50 grns
m_r : 32 grns
e : .125 in
θ : 70°

STEEL FRAGMENTS RECOVERED AFTER IMPACT ON STEEL (B~300)

V_s: 3184 fps
V_r: 0
m_s: 30 grns
$\bar{m}_r$: 17 grns
m_r: 10 grns
e : .078 in
θ : 60°

V_s: 2123 fps
V_r: 0
m_s: 120 grns
$\bar{m}_r$: 95 grns
m_r: 95 grns
e : .078 in
θ : 60°

V_s: 2029 fps
V_r: 0
m_s: 240 grns
$\bar{m}_r$: 235 grns
m_r: 235 grns
e : .078 in
θ : 70°

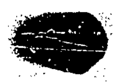
V_s: 4108 fps
V_r: 0
m_s: 30 grns
$\bar{m}_r$: 8 grns
m_r: 8 grns
e : .125 in
θ : 60°

V_s: 5248 fps
V_r: 0
m_s: 30 grns
$\bar{m}_r$: 4 grns
m_r: 4 grns
e : .125 in
θ : 60°

V_s: 3453 fps
V_r: 0
m_s: 120 grns
$\bar{m}_r$: 27 grns
m_r: 24 grns
e : .125 in
θ : 60°

V_s: 3840 fps
V_r: 0
m_s: 120 grns
$\bar{m}_r$: 8 grns
m_r: 6 grns
e : .125 in
θ : 60°

V_s: 1668 fps
V_r: 0
m_s: 30 grns
$\bar{m}_r$: 31 grns
m_r: 31 grns
e : .132 in
θ : 0°



V_s: 3269 fps
V_r: 0
m_s: 30 grns
$\bar{m}_r$: 26 grns
m_r: 26 grns
e : .247 in
θ : 0°

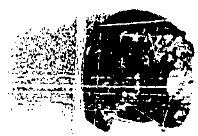
STEEL FRAGMENTS RECOVERED AFTER IMPACT ON STEEL (B~300)

V_s: 5160 fps
V_r: 0
m_s: 240 grns
$\bar{m}_r$: 5 grns
m_r: 5 grns
e : .250 in
θ : 70°

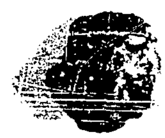
V_s: 4991 fps
V_r: 3925 fps
m_s: 30 grns
$\bar{m}_r$: 6 grns
m_r: 6 grns
e : .125 in
θ : 0°

V_s: 4810 fps
V_r: 3820 fps
m_s: 60 grns
$\bar{m}_r$: 26 grns
m_r: 26 grns
e : .125 in
θ : 0°

V_s: 2984 fps
V_r: 2265 fps
m_s: 120 grns
$\bar{m}_r$: 117 grns
m_r: 117 grns
e : .125 in
θ : 0°

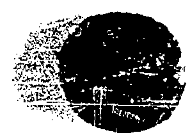


V_s: 3007 fps
V_r: 2475 fps
m_s: 240 grns
$\bar{m}_r$: 224 grns
m_r: 224 grns
e : .125 in
θ : 0°



V_s: 4945 fps
V_r: 3440 fps
m_s: 240 grns
$\bar{m}_r$: 138 grns
m_r: 138 grns
e : .125 in
θ : 60°

V_s: 4677 fps
V_r: 3870 fps
m_s: 240 grns
$\bar{m}_r$: 180 grns
m_r: 180 grns
e : .125 in
θ : 0°



V_s: 4700 fps
V_r: 3405 fps
m_s: 240 grns
$\bar{m}_r$: 173 grns
m_r: 173 grns
e : .250 in
θ : 0°

APPENDIX XI

Firing Data

Note: In each of the tabulations which follow, it is to be understood that a complete penetration of the target plate was actually experienced or else deduced from actual firings. This remark clarifies those data samples for which the residual velocity is reported as zero.

A. TUNGSTEN ALLOY FRAGMENTS IMPACTING ON ALUMINUM ALLOY PLATE

Datum No.	e (inches)	m (grains)	θ (degrees)	V_s (fps)	V_r (fps)
1	.091	240	70	987	0
2	1.000	60	0	4722	0
3	.091	60	70	1598	0
4	1.000	240	0	2801	0
5	.091	240	0	478	0
6	.500	240	0	1291	0
7	.091	60	0	586	0
8	.500	60	0	2185	0
9	.500	60	45	2717	0
10	.500	240	45	1765	0
11	2.000	240	0	5700	0
12	.250	60	0	991	0
13	.500	240	60	2169	0
14	.250	240	70	2135	0
15	.091	240	80	1234	0
16	.091	120	0	603	0
17	1.000	120	0	2831	0
18	.091	120	70	801	0
19	.091	60	60	987	0
20	.250	60	60	1968	0
21	.500	60	60	3300	0
22	.250	60	70	2884	0
23	.500	30	0	2408	0
24	.091	30	70	1382	0
25	1.000	30	0	4400	0
26	.500	30	60	4124	0
27	.250	30	70	3582	0
28	1.500	60	0	7500	0
29	2.000	120	0	8500	0
30	3.000	240	0	10000	0
31	.250	240	0	3754	3492
32	.250	240	0	3769	3500
33	1.000	240	0	3724	2486
34	1.000	240	0	3722	2391
35	1.000	120	0	4500	2500
36	.091	120	0	4871	4840
37	.091	120	0	4918	4877
38	.091	120	0	3153	3051
39	.091	120	0	3174	3091
40	.250	60	0	2867	2501
41	.250	60	0	2867	2420
42	.250	60	0	3968	3564
43	.250	60	0	4250	3954
44	.250	60	60	3213	1886
45	.250	60	60	3158	1880
46	.250	120	60	2941	1929
47	.250	120	60	3012	2167

A. TUNGSTEN ALLOY FRAGMENTS IMPACTING ON ALUMINUM ALLOY PLATE

(CONTINUED)

Datum No.	e (inches)	m (grains)	θ (degrees)	V_s (fps)	V_r (fps)
48	.500	240	60	3719	2232
49	.500	240	60	3733	2516
50	.500	60	60	4452	1142
51	.500	60	60	4452	996
52	.500	60	60	4430	1748
53	.250	240	70	3654	2324
54	.250	240	70	3635	2488
55	.091	120	70	3147	2617
56	.091	120	70	3076	2435
57	.091	120	70	4884	4412
58	.091	120	70	4910	4376

B. URANIUM FRAGMENTS IMPACTING ON ALUMINUM ALLOY PLATE

Datum No.	e (inches)	m (grains)	θ (degrees)	BHN	V_s (fps)	V_r (fps)
1	.500	240	0	120	2974	2245
2	1.000	240	0	120	3680	2058
3	.250	120	0	120	2605	2210
4	.500	120	0	120	3155	2285
5	.750	120	0	120	4133	2765
6	1.000	120	0	120	3913	1750
7	.250	60	0	120	2228	1615
8	.375	60	0	120	2828	2018
9	.500	60	0	120	3506	2365
10	.750	60	0	120	3377	1254
11	.063	60	70	120	1483	1152
12	.125	60	70	120	2930	1964
13	.125	60	60	120	2276	1647
14	.250	60	60	120	3394	2430
15	.375	240	60	120	3689	2546
16	.250	240	60	120	3552	2748
17	.250	240	70	120	3736	2500
18	.375	240	70	120	3901	1740
19	.125	240	70	120	2500	2136
20	.125	120	70	120	2658	1975
21	.250	120	70	120	3507	1861
22	.250	120	60	120	2792	1729
23	.500	120	60	120	3999	1960
24	.750	120	60	120	6202	2926
25	1.000	120	0	120	6198	4168
26	1.000	120	0	120	5356	3440
27	1.500	240	0	120	5091	1822
28	.500	240	60	120	4995	3166
29	1.000	240	60	120	5333	1223
30	.250	30	0	120	2464	1632
31	.250	60	70	120	3556	0
32	.375	60	60	120	3337	0
33	.375	120	70	120	3958	0
34	.500	120	70	120	6007	2193
35	2.000	240	0	120	5681	0
36	.500	30	0	120	4778	3105
37	.060	30	60	120	1520	1107
38	.125	30	60	120	3707	2824
39	.250	30	60	120	4991	3428
40	.500	30	60	120	5547	1999
41	.125	30	70	120	3321	2134
42	.500	240	70	120	4771	2624

C. ALUMINUM ALLOY FRAGMENTS IMPACTING ON ALUMINUM ALLOY PLATE

Datum No.	e (inches)	m (grains)	θ (degrees)	V_s (fps)	V_r (fps)
1	.125	240	0	3093	2693
2	.250	240	0	4059	3191
3	.500	240	0	4958	3506
4	.125	240	70	4075	3136
5	.072	120	60	2175	1184
6	.072	120	70	2690	1186
7	.125	120	60	2245	1176
8	.125	60	0	1813	1175
9	.072	60	60	1885	793
10	.125	60	60	3587	2021
11	.072	60	70	4026	1596
12	.500	60	0	5011	1074
13	.072	30	0	2267	1480
14	.125	30	0	2967	1446
15	.250	30	0	3366	1254
16	.072	30	60	2855	1315
17	.125	30	60	4580	1265
18	.072	30	70	3538	1057
19	.250	60	0	3904	1949

D. TUNGSTEN ALLOY FRAGMENTS IMPACTING ON STEEL PLATE (B ~ 100)

Datum No.	e (inches)	m (grains)	θ (degrees)	V_s (fps)	V_r (fps)
1	.500	120	0	2700	0
2	.500	60	0	3800	0
3	.125	60	70	2500	0
4	.250	60	0	1850	0
5	.125	60	60	1425	0
6	.250	240	0	3766	3079
7	.250	240	0	3752	2920
8	.050	240	0	1940	1898
9	.050	240	0	1913	1853
10	.250	60	0	2712	1404
11	.250	60	0	2790	1518
12	.250	240	60	4013	2491
13	.050	240	70	3514	3317
14	.050	240	70	3413	3295
15	.125	120	0	2284	1734
16	.125	120	60	3067	2100
17	.500	240	0	3619	1040

E. TUNGSTEN ALLOY FRAGMENTS IMPACTING ON STEEL PLATE (B ~ 300)

Datum No.	e (inches)	m (grains)	θ (degrees)	BHN	V_s (fps)	V_r (fps)
1	.125	60	0	370	1232	0
2	.125	60	60	370	2316	0
3	.060	30	0	410	978	0
4	.060	30	60	410	2338	0
5	.125	30	0	370	1725	0
6	.250	60	0	388	1890	0
7	.250	120	0	388	1881	0
8	.125	120	0	370	936	0
9	.500	120	0	370	3538	0
10	.500	240	0	370	2243	0
11	.060	240	0	410	656	0
12	.060	240	60	410	1054	0
13	.060	240	70	410	1674	0
14	.500	240	70	370	10000	0
15	.500	240	60	370	7000	0
16	.250	240	70	388	7000	0
17	.250	240	60	388	3669	0
18	.250	120	70	388	5000	0
19	.250	120	60	388	3145	0
20	.125	120	70	370	4224	0
21	.125	60	0	370	2989	1295
22	.125	60	0	370	3054	1492
23	.250	60	0	388	4414	3100
24	.500	120	0	370	4942	2160
25	.125	240	0	370	3835	3675
26	.125	240	60	370	3956	3400
27	.125	240	70	370	3778	1980
28	.125	240	70	370	3898	2005
29	.125	240	60	370	3870	3225
30	.250	240	60	388	3947	1665
31	.250	240	60	388	3947	1840
32	.500	240	0	370	3724	1670
33	.500	240	0	370	3629	1550

F. STEEL FRAGMENTS IMPACTING ON STEEL PLATE OF VARIOUS HARDNESSES

Datum No.	e (inches)	m (grains)	θ (degrees)	BHN	V_s (fps)	V_r (fps)
1	.060	120	60	135	2642	1830
2	.060	30	0	135	3975	3330
3	.060	30	60	135	3572	1615
4	.060	60	0	135	1291	840
5	.060	60	60	135	3935	2680
6	.060	120	70	135	3919	2450
7	.018	30	70	135	2933	2400
8	.018	30	0	135	2915	2785
9	.018	60	0	135	991	910
10	.018	60	70	135	2088	1425
11	.125	60	0	135	2899	1780
12	.125	120	60	135	4894	2815
13	.125	240	0	300	4677	3870
14	.125	60	0	300	2886	1915
15	.125	60	0	300	4810	3820
16	.125	30	0	300	4991	3925
17	.125	120	0	300	2984	2265
18	.125	240	0	300	3007	2475
19	.125	240	60	300	4945	3440
20	.250	240	0	300	4700	3405
21	.250	60	0	300	4810	2255
22	.250	240	60	300	4695	1475
23	.625	30	0	410	11500	0
24	.500	30	0	200	9000	0
25	1.000	120	0	128	9000	0
26	.500	120	70	200	9400	0
27	1.000	240	0	128	6400	0
28	.500	240	60	200	7071	0
29	.065	240	70	110	1100	0
30	1.000	30	0	128	12000	0
31	1.000	240	45	128	9000	0
32	1.500	240	0	141	9500	0
33	1.000	60	0	128	10500	0
34	.250	30	0	92	3200	0
35	.060	240	70	100	6079	4158
36	.060	240	70	100	6016	4443
37	.060	240	60	100	6067	[illegible]
38	.060	240	60	100	6050	[illegible]
39	.132	240	70	100	6045	[illegible]
40	.132	240	70	100	5902	3166
41	.132	240	60	100	6108	[illegible]
42	.132	240	60	100	6064	[illegible]
43	.132	120	60	100	5953	[illegible]
44	.132	120	60	100	5944	2549
45	.060	120	60	100	5760	3782

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F. STEEL FRAGMENTS IMPACTING ON STEEL PLATE OF VARIOUS HARDNESSES

(CONTINUED)

Datum No.	e (inches)	m (grains)	θ (degrees)	BHN	V_s (fps)	V_r (fps)
46	.060	120	60	100	6007	3976
47	.060	120	70	100	5979	2395
48	.060	120	70	100	6007	2981
49	.060	120	70	100	5893	3384
50	.060	60	60	100	5094	3280
51	.060	60	60	100	5135	3281
52	.029	30	60	100	5410	4674
53	.029	30	60	100	5325	4339
54	.029	30	70	100	5448	2576
55	.029	30	70	100	5340	3478
56	.029	30	70	100	5570	3838
57	.250	240	70	350	5000	0
58	.125	240	70	350	3000	0
59	.078	240	70	350	1750	0
60	.125	120	70	350	7000	0
61	.125	120	60	350	3600	0
62	.078	120	60	350	1900	0
63	.250	120	60	350	6500	0
64	.078	30	60	350	3300	0
65	.125	30	60	350	4800	0
66	.029	30	0	90	500	0
67	.061	30	[illegible]	90	900	0
68	.135	30	0	105	1650	0
[illegible]	.247	30	0	107	2250	0
[illegible]	.270	17	0	400	4806	0
71	.270	17	30	400	5317	0
72	.280	17	0	300	5101	0
73	.280	17	30	300	5966	0
74	.260	17	0	300	4895	0
75	.260	17	30	300	5800	0
76	.270	44	0	400	3300	0
77	.270	44	30	400	3875	0
78	.270	44	44	400	4174	0
79	.270	[illegible]	[illegible]	[illegible]	[illegible]	0
80	.270			[illegible]		
81						

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256-

					2766	0
				0	4732	0
				300	3975	0
[illegible]	[illegible]	207	0	300	2256	0
[illegible]	.270	207	30	300	2590	0
97	.270	207	45	300	3016	0
98	.270	207	60	300	3725	0
99	.270	825	0	400	1394	0
100	.270	825	30	400	1660	0
[illegible]	[illegible]	825	45	400	1591	0
[illegible]	.410	825	0	400	2346	0
[illegible]	.310	825	30	400	2399	0
[illegible]	.270	825	0	300	1564	0
[illegible]	.270	825	30	300	1695	0
[illegible]	.270	825	45	300	2094	0
[illegible]	.270	825	60	300	2507	0
[illegible]	.320	825	0	300	2984	0
[illegible]	.320	825	30	300	2973	0
110	.280	825	45	300	3437	0
[illegible]	[illegible]	240	0	332	5448	2492
[illegible]	.085	180	70	393	4174	2517
[illegible]	.060	240	70	393	5078	3751

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SUPPLEMENTARY

INFORMATION

DEPARTMENT OF THE ARMY
U.S. ARMY RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND 21005-5066

REPLY TO
THE ATTENTION OF

ERRATA

AMSRL-OP-SC-AP (380a) 15 February 1994

MEMORANDUM FOR Administrator, Defense Technical Information Center, ATTN: DTIC-HDS, Cameron Station, Alexandria, VA 22304-6145

SUBJECT: Distribution Statement for Project Thor Technical Report No. 41

1. Reference: Project Thor Technical Report No. 41, "A Comparison of the Performance of Fragments of Four Materials Impacting on Various Plates," prepared by the Ballistic Analysis Laboratory, Johns Hopkins University for the U.S. Army Ballistic Research Laboratory, May 1959, AD no. 309198.

2. Subject area experts have reviewed the subject report and have determined that it no longer contains information which requires limited distribution. Therefore the following distribution statement applies:

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3. Point of contact Mr. Douglas J. Kingsley, DSN 298-6960.

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Benjamin L. Miller
BENJAMIN L. MILLER
Chief, ARL-APG Security Office